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INVESTIGATION OF TEST METHODS,
MATERIAL PROPERTIES, AND PROCESSES
FOR SOLAR CELL ENCAPSULANTS

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JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91109

Reliability and Engineering Science Area Flat
Plate Solar Array Project

The JPL Flat Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

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I. SUMMARY

Springborn Laboratories, Inc. is engaged in a study of potentially useful low cost encapsulation materials for the Flat-Plate Solar Array project (FSA) funded by the Department of Energy and administered by the Jet Propulsion Laboratory. The goal of the study is to identify, evaluate and recommend encapsulation materials and processes for the fabrication of cost-effective and long-life solar modules.

A program of accelerated aging is being conducted for the purpose of (a) generating empirical and practical data relating to longevity, (b) rating and ranking of the stability of candidate formulations, and (c) generating data that may be used in mathematical models for the prediction of service life.

Although a variety of aging methods are being used for this work, the use of Outdoor Photo Thermal Aging Reactors (OPTAR) appears to be the most promising. These devices age polymers in natural sunlight while accelerating the degradation reactions with heat. They are on only during the sunlight hours and are currently operated at 70°, 90° and 105°C. The OPTAR technique appears to be the most useful yet discovered for assessing the relative aging performance of encapsulation materials in reasonably short periods of time. Some candidate pollutants may be degraded in as little as 2,000 hours (@ 105°C), and advanced formulations have been discovered that extend this mean time to failure. Comparative aging studies have successfully identified a new oligomeric hindered amine light stabilizer (HALS) (Cyasorb UV-3346, American Cyanamide) as having potential for further extending the service life of present EVA compounds.

The OPTAR method was initially intended for use in the evaluation of whole modules. Modules containing four pollutant formulations have been under exposure for 5,000 hours and examination indicates that the most destructive effect at any temperature is the presence of metallic copper. Apart from this effect, no changes are observable in the modules exposed at 70°C. At 90°C, the two EVA formulations cured with Lupersol-101 peroxide show signs of discoloration and slight corrosion of the metallic components is also apparent. All the modules are in generally good condition. At the 105°C exposure the signs of degradation

are more obvious. The presence of copper causes a violent degradation reaction, however it does not spread far from the location of the metal. All the pottants tend to discolor at this temperature. The effect is pronounced in the EVAs cure with Lupersol 101, but slight in those cured with Lupersol-TBEC. Other observable changes are slight corrosion of the interconnects and breakage of the glass outer covers due to thermal shock. The power generating ability of all the modules seems to be unimpaired. These experiments definitely demonstrate the improvement in performance that occurs when all the encapsulation components are combined to mutually protect each other. Finally, lifetime modelling experiments performed with the OPTAR devices appear to be extremely encouraging. Using unstabilized polypropylene as a model compound, a linear relationship (Arrhenius) was found when the induction period, $\log t_i$, was plotted as a function of reciprocal temperature. This function has been successfully extrapolated to the known lifetime of this polymer under ambient conditions. If this relationship is found for pottant formulations, then reasonable predictions of real time service life may become possible.

Experiments were continued in the area of primers and adhesion, but with an emphasis on bonding diagnostics and durability rather than formulation development. A fine spherical monodisperse glass powder was treated with silane coupling agent and blended into EVA resins to give compounds containing a high concentration of bonded surface area. Parallel sets of specimens were then hydrothermally aged by water immersion at three temperatures and removed for testing at fixed intervals. One set of specimens was measured for physical and mechanical properties, the other was sent to Case Western Reserve University for spectroscopic (DRIFT) analysis in an attempt to examine shifts in the surface chemistry. Additionally, a set of specimens was dried in an air oven and used to determine the reversibility of any bond damage that may have occurred. Although changes in mechanical properties were found (tensile strength, elongation, modulus) the most dramatic property variation was change in weight due to absorbed water. Higher temperatures and longer times resulted in higher weight gain. The highest weight gain, 2,015%, was found for unprimed glass beads in EVA after 2,000 hours in 60°C water. The equivalent specimen with primed glass showed only 34.7% weight gain, clearly showing the difference between bonded and unbonded surfaces. High weight gains of water also corresponded to the decay of mechanical properties, the largest effect being the decrease in elongation at

break. Specimens dried in an air oven to constant weight indicate that wet strength is reversible to dry strength in specimens with the primed glass surface, and most properties return to their control values. Although still exploratory, hydrothermal aging of high surface area glass filled polymers shows promise as a diagnostic tool for the evaluation of primer compositions.

Flammability of modules is of concern due to their potential for lowering the flame resistance of other roofing structures in residential applications. A number of approaches to the solution of this problem are conceivable, including reduction of the amount of combustible material used in the construction of a module and the incorporation of fire retardant compounds to quench the combustion. Fire retardant agents were blended into EVA in an attempt to create self-extinguishing compositions. Additives were selected on the basis of well documented compositions known to be effective in polyolefins. First-cut testing using UL-94 vertical burn identified some formulations as V-0, self extinguishing. Compression molding of these formulations with "Craneglas" cloth to further dilute the organic content and improve strength resulted in flexible sheet compositions with limiting oxygen index values of 30%. This is approximately equivalent to silicone rubber in flammability, and higher ratings are believed to be possible.

Pottants and other module components must perform a wide variety of functions, one of which is electrical insulation. Loss of adequate insulation could result in excessive leakage current resulting in electrochemical corrosion, ground-fault arcing and an electrical safety hazard. Due to the importance of electrical insulation, measurements of the effects of aging on this property are important. Laboratory techniques for the measurement of the "intrinsic dielectric strength" were developed and plots of DC breakdown voltage versus thickness yielded linear plots. Experiments will continue with the testing of aged specimens to determine if the breakdown strength changes with environmental stress.

An experimental program is continuing to determine the usefulness of soil resistant coatings. These coatings are intended to be surface treatments applied to the sunlight side of solar modules and function to prevent the persistent adhesion of soil to the surface, aid in its removal, and consequently

keep the power output high. These treatments have been applied to "Sunadex" glass, "Tedlar" polyvinyl fluoride film and "Acrylar" oriented acrylic film. The treatments are based on fluorosilane chemistries. After thirty-eight months of outdoor exposure, a fluoro treatment designated E-3820, was found to be the best coating for all three outer surfaces and result in significantly better soil resistance than the controls. This material still appears to be active after three years, whereas the other candidates have all lost their effectiveness. Based on standard solar cell measurements, the improvement in power output using this treatment is estimated to be about 1% for Sunadex glass, 3.8% for Tedlar and 3.9% for Acrylar. These treatments may provide a passive and cost effective way to maintain high power for PV arrays in the field.

Outer cover films are required for the protection of substrate designed modules in which the cells are supported from the underside. The outer cover must be highly transparent and weatherable. Initially, it was thought that UV screening was also a necessity, however most of the candidate pottants appear sufficiently stable so that the additional protection may not be required. This now expands the number of materials that might be suitable for this application. Some of the more expensive fluoropolymers may still be cost effective due to their low refractive indices. The improvement in optical coupling may result in an increase in module efficiency of several percent. Some of these newer candidates will be evaluated further in future work.

A new section has been added to this program entitled "Process Sensitivity". The goal of this study is to examine the relationships between material and process variables and to determine the acceptable "windows" that result in modules of predictable quality. A microprocessor controlled vacuum laminator has been constructed for this study that will enable processing variation under software control. Laminations conducted with a standard test module will be used to evaluate the effect of specific variables.

Work on formulation variables is underway. Experiments have been performed to assess the effects of storage of EVA pottants. The results indicate that EVA 9918 is rapidly affected by exposure to the open air. Exposure of the fast-cure formula, EVA 15295, is much less detrimental; however, a gradual decrease in its ability to cure is observed. It is recommended that all EVA products be kept wrapped in a closed plastic bag for storage, and also at the end of each day of production. When stored in this manner, there does not appear to be a limiting shelf life.

II. INTRODUCTION

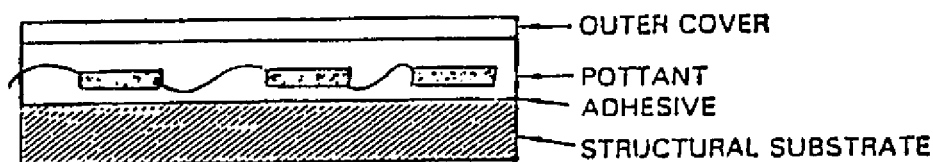
Photovoltaic modules consist of a string of electrically interconnected solar cells capable of producing practical quantities of electrical power when exposed to sunlight.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components. The encapsulation system is defined as all the construction materials required in a module to provide this mechanical support and environmental isolation. In addition, the module must be based on construction materials and design considerations that meet the field operating requirements while also minimizing the cost.

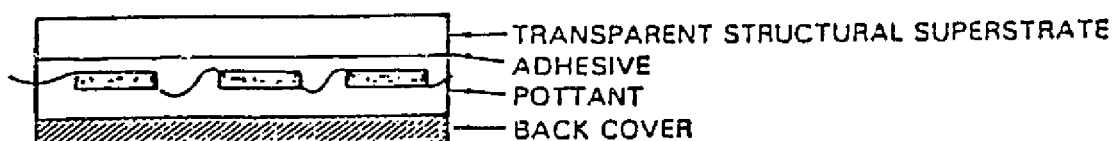
Assuming the flat-plate collector to be the most efficient design, photovoltaic modules are considered to be of two basic types, substrate and superstrate, and to be composed of seven basic construction elements. The design types are diagrammed as follows:

BASIC MODULE TYPES

SUBSTRATE-BONDED



SUPERSTRATE-BONDED



The seven basic construction elements are : (a) outer covers, (b) transparent superstrates, (c) pottants, (d) substrates, (e) back covers, (f) gaskets and edge sealing, and (g) adhesives or primers.

Throughout this program, extensive surveys have been conducted into many classes of materials in order to identify the compound or class of compounds optimum for use as each construction element.

The results of these surveys have also been useful in generating first-cut cost allocations for each construction element, which are estimated to be as follows (1980 dollars):

<u>Construction Elements</u>	<u>Approximate Cost Allocation* (\$/m²)</u>
Substrate/Superstrate (Load Bearing Component)	\$ 7.00
Pottant	1.75
Primer	0.50
Outer Cover	1.50
Back Cover	1.50
Edge Seal & Gasket	1.85

From the previous work, it became possible to identify a small number of materials which had the highest potential as candidate low cost encapsulation materials.

In addition to materials, two fabrication processes have been explored: vacuum bag lamination and liquid casting. In vacuum bag lamination the pottant is handled as a dry film of formulated polymer that is used to sandwich the cell string. Encapsulation is completed by the application of vacuum and heat. In the casting process the pottant is handled as a high viscosity liquid that is pumped around the cell string. For both, curing to a rubbery solid is accomplished by the application of heat.

* Allocation for combination of construction elements: \$14/m².

Program efforts have emphasized the identification and development of potting compounds. Pottants are materials which provide a number of functions, but primarily serve as a buffer between the cell and the surrounding environment. The pottant must provide a mechanical or impact barrier around the cell to prevent breakage, must provide a barrier to water which would degrade the electrical output, must serve as a barrier to conditions that cause corrosion of the cell metallization and interconnect structure, must protect against conditions that cause corrosion of the cell metallization and interconnects, and must serve as an optical coupling medium to provide a maximum light transmission to the cell surface and optimize power output. Due to its central role in the encapsulation scheme, the pottant has received more emphasis than any other construction element, however other components and module related activities are now under investigation. Of particular importance are areas relating to module reliability and prediction of the service life. Additionally, another area of study entitled "Process Sensitivity" has been added to this contract. Its purpose is to determine the degree to which formulation and processes affect the module quality and manufacturing yield. This report presents the following topics:

In Section A:

- (1) Aging and Life Prediction methodology and devices.
- (2) The function of adhesion chemistry, primers and a new diagnostic technique for estimations of bond durability.
- (3) A study of fire retardant formulations for decreasing the potential flammability of solar modules.
- (4) The initial studies of the electrical insulating properties of encapsulation materials and measurement of the intrinsic dielectric strength.
- (5) Anti-soiling compounds for the prevention of soil build-up on the outer surface of the module.
- (6) Low temperature processing encapsulants that permit module fabrication at temperatures less than 100°C.

In Section B:

- (1) The background and statistical methods for relating process variables to dominant failure mechanisms and their use in predicting manufacturing yields.

SECTION AIII. AGING AND LIFE PREDICTIONA. Background

The candidate encapsulation materials being investigated in this project are intended for the construction of solar cell modules for terrestrial deployment and consequently must be capable of enduring the operating temperatures, insolation, precipitation and other elements of the outdoor exposure in the geographical region selected. Although the severity of these conditions may be fairly accurately gauged (climatic atlas, weather records, etc.) the lifetime and performance of individual materials or combinations of materials is not as easily assessed. The chemical pathways and rates at which materials age in outdoor exposures are very complex and predictive techniques often turn out to be inaccurate.

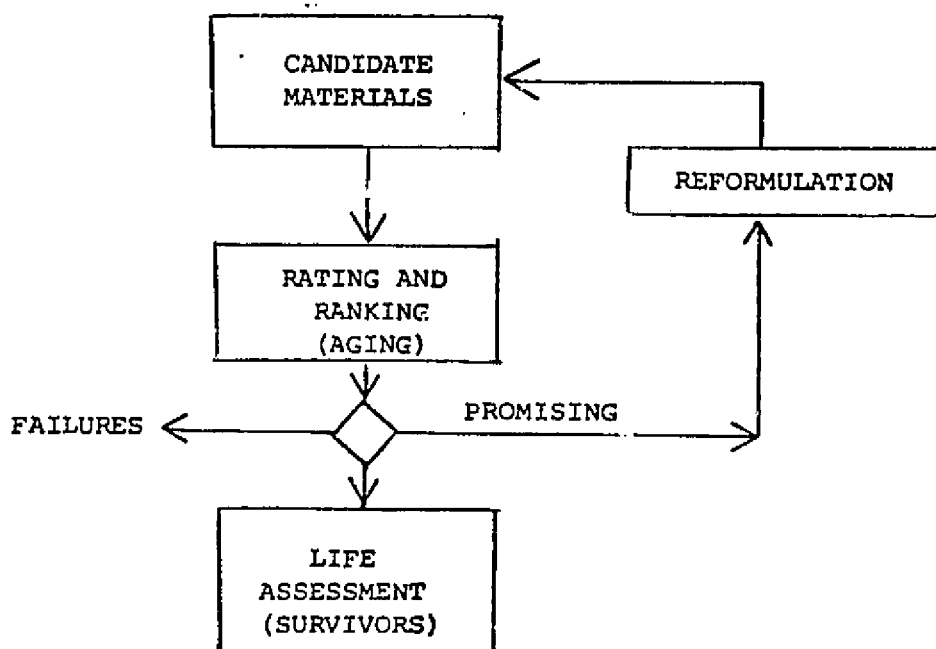
The degradation of polymeric materials in outdoor weathering is caused primarily by sunlight, especially the ultraviolet component. The deteriorating effect of light is usually enhanced by the presence of oxygen, moisture, heat, abrasion, etc. and is more accurately referred to as photooxidation, resulting from the combined effects of oxygen and sunlight. Sunlight at the earth's surface (filtered by the ozone layer) begins at 290 nm in the ultraviolet and continued through the visible ranges out to approximately 2,600 nm in the infrared. It is the ultraviolet portion of the spectrum (290 to 400 nm) that results in most of the photo-induced changes in polymeric materials.

Plastics vary considerably in their ultraviolet absorbing properties, but few are completely transparent in the 290 to 400 nm range. Once the radiant energy has been absorbed, the likelihood of chemical action will depend on the degree of absorption and the stability of the chemical bonds in the polymer. The induced chemical modifications are responsible for the deterioration of optical and mechanical properties and usually result in reductions of tensile strength, elongation and transparency. Specially formulated stabilizers are frequently used to interrupt this degradation chemistry and extend the service life of the polymer.

Accelerated tests are also used to assess long term aging effects and compare the effectiveness of stabilizers in providing improved protection against environmental deterioration. Typically, properties such as tensile strength, elongation at break, apparent modulus, resistance to flex cracking and other properties are measured on samples aged for known periods of time under specified conditions. These tests are useful for determining the relative stability of polymers and formulations, however correlation with actual service life is infrequent.

In order to assess the relative stability of individual polymers and to determine the effectiveness of varying formulations, Springborn Laboratories is conducting a program of accelerated aging and life predictive strategies that should be useful for : (a) rating, ranking and reformulating candidate encapsulation materials, (b) generating practical data that relate to material performance under use conditions, and (c) generating data that may be useful in some type of predictive manner for life assessment.

The goals are being met by using the scheme presented in the following diagram:



This method is intended to serve as a multipurpose data source.

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The stresses to which materials are exposed consist of the following, either singly or combined:

- (a) Thermal stress (heat aging)
 - . in inert atmosphere
 - . in air
- (b) Ultraviolet stress (UV exposure)
- (c) Hydrolytic stress (water exposure)
- (d) Catalytic stress (metal catalyzed oxidation)
- (e) Combined stresses (any of the above together)

The effects of these stresses on the candidate encapsulation materials is determined by measuring specific properties as a function of time. These properties were selected for their relevance to module service life and were chosen from four categories considered to be potentially life-limiting, as follows:

- . Mechanical: tensile strength, elongation, gel content, modulus
- . Optical: yellowing, haze, optical transmission from 0.4 to 1.1 microns
- . Chemical: loss of stabilizers, degradation, corrosion of interconnect metalization, metal catalyzed reactions, outgassing
- . Dielectric: field stress degradation, decay of breakdown strength, leak current, loss of electrical isolation

For the evaluation of individual materials and/or combinations of materials, a number of exposure conditions have been used, including oven (thermal) aging, RS/4 fluorescent sunlamp at 50°C and 85°C, JPL's Controlled Environment Reactors (CER) and outdoor site exposures.

The details of these experiments and the results obtained have been documented in previous reports.^(a) These methods have been useful for some

(a) Willis, "Investigation of Test Methods, Material Properties and Processes for Solar Cell Encapsulants" Annual Reports No. 6 through 8, 1982-1984, Springborn Laboratories, Enfield, CT.

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comparisons of the relative durability of materials, but within particular limitations. These are:

- (a) The use of light sources that do not duplicate the sun's spectrum and have an inconsistent output with respect to time (lamp darkening).
- (b) Exceedingly long exposure times are required (sometimes several years) are required before the test specimen shows any sign of degradation.
- (c) Unpredictable correlations between test exposure conditions and actual outdoor field exposures.
- (d) Conditions that do result in relatively rapid degradation introduce overstresses that may now introduce chemical mechanisms that would not be found in field operations.
- (e) In general, the conditions are too "artificial" and do not resemble outdoor environmental conditions.

B. OPTAR Devices

Due to these objections, a different approach was considered to the aging of candidate encapsulation materials - the use of Outdoor Photo Thermal aging devices (OPTAR). These are devices recently constructed at Springborn Laboratories that constitute a new approach to accelerated weathering. (a)

The predominant cause of outdoor deterioration is photothermal aging; the combination of heat and ultraviolet light. In all the laboratory techniques devised to date, it is mainly the light that is increased (photoacceleration) through the use of arcs and discharge lamps. In the OPTAR reactors, natural sunlight is used as the light source and only the specimen temperature is increased. The OPTAR reactors consist of heated aluminum blocks surfaced with stainless steel and mounting hardware to hold the test specimens flush with the surface. The reactors are tilted at 45° south and the device turns on

(a) Subject of a paper to be published in fall of 1985.

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at sunrise and off at sunset. Three temperatures have initially been selected: 70°C, 90°C, 105°C. This approach eliminates the difficulties associated with the irregular spectrum of artificial light sources, exposes the specimens to other environmental conditions such as rain and pollution, and additionally incorporates a dark cycle. The only acceleration, therefore, is in the temperature, all other environmental conditions being present in their natural occurrence and intensity. In summary, the OPTAR device is considered to have the following advantages:

- (a) "uses natural sunlight, therefore avoids the spectral distribution problems encountered with artificial light sources,
- (b) uses temperature to accelerate the photothermal reactions and is easily controllable,
- (c) includes dark-cycle reactions that are a natural part of field exposure,
- (d) includes dew and rain water extraction effects,
- (e) more closely resembles the environmental conditions experienced by solar modules,
- (f) easily accommodates both discrete materials and entire modules, and
- (g) may be set at any temperature desired for the purposes of varying the acceleration rate or extrapolating to lower temperatures."

Blueprints used in the construction of the OPTAR devices were published in a previous report. ^(a)

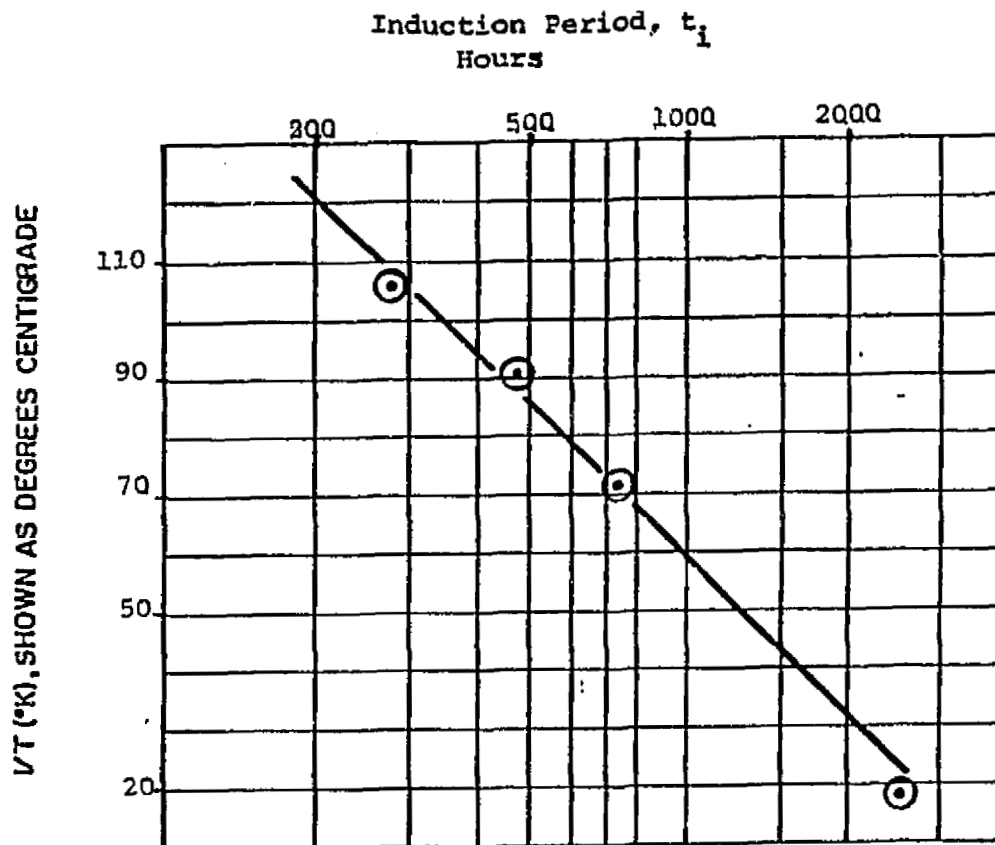
C. Predictive Modelling

A number of approaches to data modeling may be considered, the simplest being first order behavior in which the log of the property being measured is linear over time. This relationship may be used easily for life prediction,

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- (a) Willis, "Investigation of Test Methods, Material Properties and Processes, for Solar Cell Encapsulants", DOE/JPL 954527-27/84

especially when the rate constant is Arrhenius in nature. Polymer degradation is frequently a complex relationship of many competing chemical reactions, however, and may shift dramatically with subtle changes in temperature, light intensity, additives, etc. The behavior most frequently observed is the "induction period" type in which the degradation rate suddenly changes the property vs time curve shows a sharp downward trend. The time to the onset of this change is the induction period and is often used to measure the efficiency of antioxidants, (isothermal DTA). This approach was used in modeling the OPTAR conditions with the assumption that the mechanism of degradation is consistent over the 70°C to 105°C range.

Polypropylene was selected as a model polymer for this test due to the fact that its induction period, t_i , is sharp and easily measured. This is shown as a sudden drop in the elongation at break. Tensile bars of unstabilized compression molded polypropylene were placed on the OPTAR devices at the three temperatures and the log of the induction period measured as a function of reciprocal absolute temperature. The following graph shows that the relationship is linear and a close approximation to the Arrhenius function exists.

OPTAR Degradation of Polypropylene

This data is extremely encouraging and suggests that wherever an induction period can be identified, the possibility for predictive modeling exists. Statistical extrapolation through these points to a mean ambient temperature of 20°C gives a predicted life (induction period) of 2,300 hours (three months), which is known to be the actual life of polypropylene in outdoor aging at the same exposure site. This fact adds to the credibility of this method, however more data must be taken (and with different polymers) to thoroughly validate this approach.

D. Module Exposure

The OPTAR devices were constructed mainly for the aging of experimental solar modules. Accelerated aging using this method should be useful for studying the stability of the encapsulation package resulting from the combination of the individual components. If the aging module shows some type of induction period phenomenon, then it may be possible to predict the module service life in a manner analogous to that presented for polypropylene. This method may also indicate the maximum service temperature that can be tolerated over the desired thirty year life.

Four types of "mini" modules were prepared of 5"x8.25" size, each containing two interconnected 90 mm diameter solar cells (Solar Power Corporation, Woburn, MA). Each module consisted of the following components; (a) glass primed with 11861 primer, (b) the EVA formulation, (c) the cell pair, (d) the second layer of EVA, and (e) a back cover film of white Tedlar (200BS30WH) coated with 68040 adhesive.

The modules were prepared by a vacuum bag lamination technique and four EVA formulations prepared, each to test a formulation variables, as follows:

Modules Under Exposure

<u>Module Number</u>	<u>Pottant Formulation No.</u>	<u>Description</u>
16747-1	EVA A9918	Standard Formulation: (Lupersol 101, UV-531, Tinuvin 770)
16747-2	EVA 16718A	Advanced EVA Formulation: (TBEC, UV-2098, Tinuvin 770)
16747-3	EMA 16717	Advanced EMA Formulation: (TBEC, UV-2098, Tinuvin 770)
16747-4	EVA 14747	Experimental EVA Formulation: (Lupersol 101, UV-2098, Tinuvin 770)

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In addition, each module was prepared with a 1" x 0.75" piece of untreated copper mesh encapsulated in the pottant to determine the severity of copper activation effects. The modules were evaluated by visual inspection. Tables of results appear in the appendix, pages 1 through 12.

The following table gives the general results of module performance on OPTAR reactors after 12,000 hours of exposure.

OPTAR Exposure: Modules

12,000 Hours

<u>Number</u>	<u>Pottant</u>	<u>Component</u>	<u>70°C</u>	<u>90°C</u>	<u>105°C</u>
16147-1	EVA A9918	Pottant	1	A2	A4
		Copper	A4	A3, E3	A5, E5
		Glass	1	1	B
		Metalization	1	C2	1
16147-2	EVA 16718A	Pottant	1	D2	A2
		Copper	1	A2	A5
		Glass	1	1	B
		Metalization	1	C2	1
16718-3	EMA 16717	Pottant	1	D2	A4
		Copper	1	A2	A5
		Glass	1	1	B
		Metalization	1	1	1
16718-3	EVA 14747	Pottant	1	A3	A4
		Copper	A2	A4	A5
		Glass	B	B	B
		Metalization	1	C3	C3

A = discoloration
 B = broken/fractured
 C = corrosion (metalization)
 D = delamination
 E = flow/melt

1 = no change
 2 = slight change
 3 = noticeable
 4 = moderate
 5 = severe

When aging effects were observed, the first change to be noticed was slight discoloration in the vicinity of the copper mesh. This was also anticipated to be the first source of degradation. At 70°C it is barely noticeable after 5,000 hours and is found in two modules (EVA A9918, EVA 14747). Apart from this slight effect, there are no other changes that can be observed in any of the modules at the 70°C/12,000 hour condition.

At 90°C the copper discoloration became noticeable in all modules (both using Lupersol-101 as the curing agent), and at 105°C was dramatically visible in all four. In addition to the strong orange/brown color around the copper mesh, signs of flow of the pottant could also be found, especially in the module using EVA A-9918. In the 90°C/12,000 hour condition, a few other effects also became noticeable. Some discoloration (yellowing) of the pottant was found in the module prepared with EVA 9918 and EVA 14747. Both of these formulations have the similarity of being cured with Lupersol-101, which suggests that this curing agent might result in slightly less photostable compositions than the Lupersol-TBEC used in the other two compositions.

Also at 90°C, small amounts of corrosion (presumably) around the interconnects, could be noticed in the form of slight haze and yellowing. These areas are very small, however, and do not appear to threaten the electrical functioning of the module. Interestingly, these "corrosion" effects were not noticed in the 105°C exposure.

At the 105°C/12,000 hour test point, degradative effects were now quite noticeable. The glass outer covers all showed meandering cracks due to thermal shock, the copper catalyzed degradation of the pottant was striking and all the pottants showed some degree of discoloration.

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No broken cells, or change in the electrical functions, was found in any of the cells. Of the four formulations tested, the least amount of change was found in the module fabricated with EVA formula 16718A. This is an experimental "advanced" formulation cured with Lupersol-TBEC and containing the co-reacted UV-2098 ultraviolet screener and Tinuvin-770 HALS compound. These experiments have proven to be very useful in, (1) demonstrating the performance enhancement of advanced formulations, and (2) showing that the encapsulation components are much more stable when combined into a module than when exposed alone. This is the purpose of encapsulation; to provide a combination of materials that mutually enhance each others service life in order to maximize module performance. These experimental modules will continue under OPTAR exposure until total loss of electrical output is observed.

IV. ADHESION AND PRIMERS

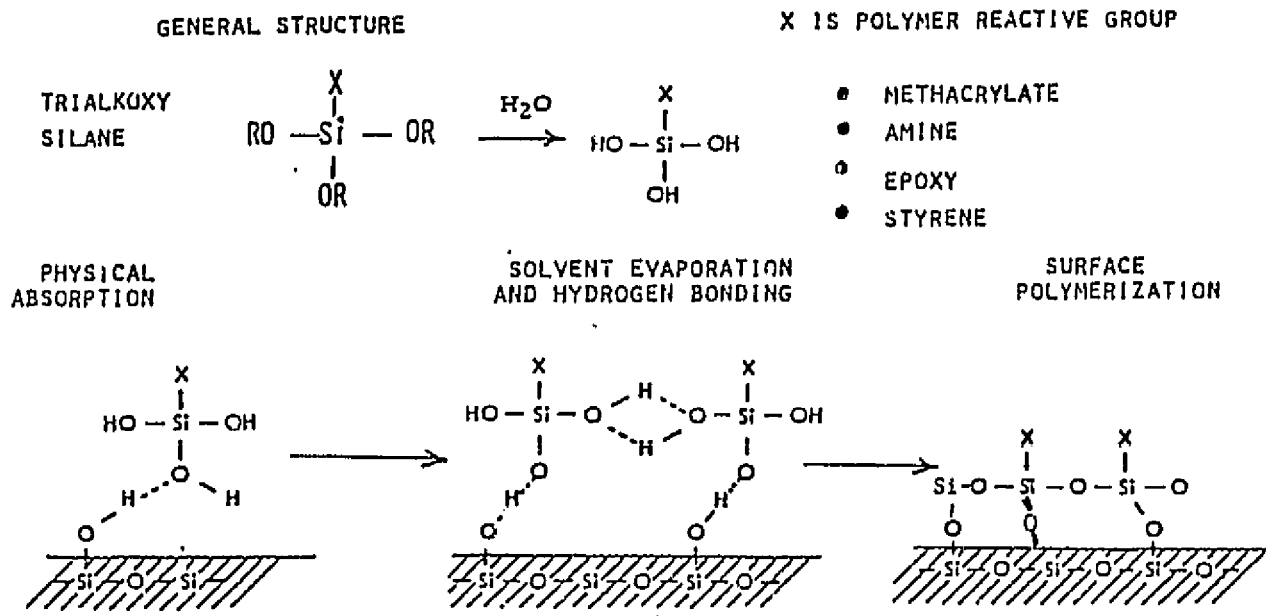
A. Background

Adhesives and primers are necessary for the high reliability bonding of module interfaces to insure the structural integrity and long life. The adhesion between the pottant and other components, i.e., substrate, superstrate and outer cover, must have adequate bond strength to hold the module components together, but must also last for the service life of the module. Bond durability is, therefore, a key consideration. Work over the past few years has emphasized highly successful primer formulations based on silane (organic/silicon) compounds.

A primer operates by creating a reactive chemical interface between two components, whereas an adhesive is a discreet compound that constitutes a separate phase to which the two other components may bond. Primers have been emphasized in the bonding studies due to a number of advantages they present in use. Primers are (a) used in exceedingly small quantities, (b) are cost effective, are (c) easily applied to surfaces, (d) function by the formation of high strength chemical bonds, and (e) may possibly be combined into the pottant systems to eliminate the priming step.

Silane coupling agents have the general formula of: $Y-(CH_2)_3-Si-(OR)_3$ in which Y is a group that is functionally active with the polymer side of the interface and the (OR) groups are short chain silyl ethers that react with the glass. These ether groups must be hydrolyzed first to give silanol (Si-OH) groups that may then condense with themselves and with the hydroxyl groups on the glass surface. In practice, the primer solution consists of a water or alcohol solution containing about 1% of the active silane compound. This solution is applied to the surface to be primed and permitted to dry. The chemistry is diagrammed as follows:

BONDING OF SILANE COUPLING AGENTS TO GLASS



After the bond formation is complete it may be considered to be a series of layers consisting of;

- (a) the bulk glass substrate,
- (b) the bonded interface between the glass and the silane primer,
- (c) the condensed polysiloxane interphase,
- (d) the interpenetrating network between the primer and the polymer, and
- (e) the bulk polymer phase..

The success of silane coupling agents as primers for bonding polymers to mineral surfaces is well documented and they are widely used in commercial practice.

B. Bonding Diagnostics

Although EVA and other pottant materials have been efficiently bonded to glass and other module components, very little is known about the bond durability and the service life.

Like any other adhesive bond, these interfaces may fail when exposed to overstress conditions. These stresses may be mechanical, chemical or a combination of the two. Due to the very low stress levels that exist in the solar module application, the degradation forces are considered to be primarily chemical in nature and result from exposure to heat and moisture.

Test specimens were prepared to determine the effects of hydrothermal aging (heat and water) on glass/primer/EVA bonds. These specimens were designed for use in a parallel program in which the decay of mechanical properties (bond strength) could be measured with simultaneous spectroscopic investigation of the interface to follow the chemistry. The specimens were prepared by dispersing high loadings of extremely fine, essentially spherical glass powder^(a) in the EVA and curing as usual to "set" the bond chemistry.

The test specimens consisted of both primed and unprimed glass powders and both EVA (Elvax 150) and polyethylene were used as the polymers. The glass powders were first washed in dilute mineral acid to remove alkaline residues on the surface, then dried and treated with primer^(b) until a total of two weight percent of active primer was deposited on the surface.

(a) Potter's Industries, Hasbrouck Heights, N.J. Product No. 5000. Spherical A-glass powder, 400 mesh, mean particle diameter appx. 20 μ , mean surface area, 0.269 m²/gm.

(b) Springborn Laboratories primer No. All861; consisting of 90% Dow Corning Z-6030, 9% of Benzyl dimethylamine catalyst and 1% Lupersol TBEC peroxide. These active ingredients are dissolved in methyl alcohol to give a 1% solution. Equivalent to approximately 100 monolayers of silane.

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The treated glass was then used to prepare the following formulations:

Adhesive Bonding Test Formulations

	<u>18181-A</u>	<u>18181-B</u>	<u>18181-C</u>	<u>18181-D</u>
Elvax 150 (EVA)	100	100	--	--
Chemplex 6230 polyethylene	--	--	100	100
Lupersol TBEC	1.5	1.5	1.5	1.5
Glass 17468-A (no primer)	110.8	--	110.8	--
18180-Primed glass beads	--	110.8	--	110.8
Volume % loading	30%	30%	30%	30%
Cure: 150°C/20 minutes	- - - - - all - - - - -			

Tensile bars were cut from cured molded plaques and then exposed to hydrothermal aging conditions by immersion in water at the following times and temperatures:

Hydrothermal Aging Conditions

<u>Water Temperature</u>	<u>Hours</u>					
	<u>100</u>	<u>250</u>	<u>500</u>	<u>1,000</u>	<u>2,000</u>	<u>5,000</u>
40°C	X		X		X	X
60°C	X	X	X		X	
80°C	X	X	X	X		

The test bars resulting from these exposures were then tested for mechanical properties before and after drying and small samples were also sent to Case Western Reserve University, Cleveland, Ohio for spectroscopic examination.

A spectroscopic method for examining the bond chemistry has been developed at Case Western and is the topic of forthcoming papers.^(c) This method employs "DRIFT" analysis, in which a diffuse-reflectance cell is attached to an FTIR spectrometer. This device measures the reflectance spectrum from the surface in which the intensity of the reflectance at a given wavelength is directly proportional to the molar absorption of the active species. Studies at Case Western have determined that;

- (1) as little as 0.05% primer on the glass spheres may be detected,
- (2) 1% of the primer (approximately 50 monolayers) appears to be a good measurement range,
- (3) the amine catalyst (benzyl dimethyl amine) is extremely effective in condensing the silane at the interface and results in hydrothermally stable bonds, and
- (4) the acrylate group of the primer appears to polymerize during the cure to form an interpenetrating polymer network (IPN) with the EVA polymer.

Although the data is incomplete at this time, no major differences are found in the spectra of the hydrothermally aged specimens except for the apparent uptake of water in the material. This is speculated to be water trapped at the surface of the glass/polymer interface and is fairly resistant to drying. Further details will become available as Case Western continues their work.

Springborn Laboratories has almost completed physical measurements on the hydrothermally aged test specimens. The properties measured are:

- Modulus (1% strain)
- Ultimate tensile strength
- Ultimate elongation
- Dimensional change (length)
- Weight change (water absorption)

(c) J.L. Koenig, E.F. Cuddihy, P. B. Willis "Spectroscopic Studies of Chemical Bonding for Terrestrial Photovoltaic Modules", pending publication.

These measurements are tabulated for each temperature in tables 13 through 18 in the appendix. In addition, a second set of tables is included which gives the results from a separate set of test specimens dried at 105°C for a period of 72 hours. The purpose for this was to determine the extent to which the bond strength was reversible by simply removing the absorbed water.

At 40°C water immersion, little effect was noticed for all the formulations except for 18181-A (EVA containing unprimed glass beads). This specimen slowly increased in water absorption from +0.15% weight gain after 100 hours to +51% weight gain after 2,000 hours. Apart from a minor decrease in elongation, the properties of this compound remained unchanged: The 60°C water immersions were found to be more severe, and now both the compounds with and without primer began to respond. The EVA containing 30 volume % of glass beads gained an enormous +2,000% increase in weight at the 2,000 hour test point. The mechanical properties also shifted dramatically at this point and the compound lost 90% of its modulus, 96% of its tensile strength and about 90% of its elongation. The equivalent compound with primed glass only gained +35% in weight, and most of the other properties were only slightly affected. The equivalent polyethylene specimens gained only 3-4% water and were unaffected by the immersion. In the case of EVA, the difference between primed and unprimed glass filler is very noticeable and suggests that the properties at the interface (adhesion bond) are responsible for the observed effects. The next immersion temperature was 80°C and resulted in rapid deterioration of the EVA specimens containing unprimed glass. After 500 hours, the specimen had increased 500% in weight, and lost 80% of its tensile strength and elongation. Due to softening and tearing, this specimen did not survive the 1,000 hour immersion test point and was removed from further exposure. The EVA formulated with primer beads gained 61% by weight of water at the 1,000 hour test point and retained most of its other properties reasonably well. As with the previous experiments, the polyethylene compounds loaded with primed and unprimed glass beads showed only small gains from water absorption and were virtually unchanged.

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It appears that the surface of the glass or the interface between the glass and the polymer is extremely hygroscopic and is effective in trapping large amounts of water in the polymer. The primer is of help in inhibiting this phenomenon and seems to give at least a ten fold reduction in the amount of water absorbed. Water absorptions in the bulk polymer without fillers has been determined in a previous set of experiments. For EVA, the equilibrium water content at 40°C and 60°C is in the order of +0.3%. At 80°C pure EVA (Elvax 150) equilibrates at approximately 1% by weight water. These water absorption experiments indicate that the glass/polymer interface is the region affected.

A second set of test bars from the water immersion tests were dried to determine the extent of property recovery and give an indication as to when permanent and non-reversible damage had occurred. The results of these experiments are given in tables 16 through 18 in the appendix. For the 40°C immersions, all the specimens recovered almost all their original properties. At 60°C signs of permanent damage now became apparent in the EVA specimen filled with unprimed glass beads. At the 500 hour point, the tensile strength decreased by 30%, and at the 2,000 hour point had decreased to 65% of control. About a 50% reduction of elongation at break was also found at this point. The other EVA compound containing primed glass recovered most of its control properties upon drying. The 80°C test specimens gave much the same performance except now non-reversible effects seem to start at after about 250 hours in the unprimed glass/EVA specimen. Primed EVA/glass specimens survived 2,000 hours at this temperature without damage.

Although still in the exploratory stage, hydrothermal aging of glass filled polymer compositions in showing promise as a new method for evaluating the effectiveness of primers at interfaces. Good primers appear to keep the water absorption at lower values, affect other measurable physical properties and may indicate the relative level of hydrothermal damage to the adhesive bond by the reversibility upon drying. If the spectroscopic examination of these specimens at Case Western Reserve gives data that parallel these findings, then a new non-destructive method for diagnosing the stability of adhesively bonded interfaces may have been discovered.

V. FLAMMABILITY

A. Approaches

Flammability of solar cell modules has been an area of growing interest for the past two or three years. Although solar modules themselves contribute little to the quantity of combustible material in roofing structures, it has been demonstrated that under certain conditions they may play a role in reducing the flame resistance of existing roofing materials. In the worst case scenario (ground fault arcing) they could even serve as an ignition source. One of the standard tests for the acceptability of roofing materials with respect to fire codes is the Underwriters Laboratories UL-790 test. In part of this test procedure, a burning "brand" of wood is placed directly on the structure observed. Different types of solar modules have been tested using this procedure and, in cases, the results have not been favorable. It appears that the pottant, when ignited, may result in the spread of fire.

A number of approaches to the solution of this problem are conceivable, including (a) reduction of the amount of combustible material used in the construction of a module (b) the incorporation of fire retardant compounds to quench the combustion and (c) the use of containment techniques to prevent the burning components from reaching the roof below the module.

- (a) In the first idea, two techniques (or combination of the two) are foreseeable. The flammable components of the module (pottant) may be reduced by thinning the pottant layers. This may be possible by simply extruding thinner sheet compound from which the module is constructed. If absolutely required, the base resin of the pottant could be changed to a lower melt index material that could be extruded into a thinner profile.

Thinning the pottant is a major step towards removal of combustible materials in PV modules. Springborn Laboratories will determine the extent to which the pottant thickness may be reduced. The second idea is the use of inherently non-combustible materials. For substrate designed modules, the use of transparent fluorocarbon films is a possibility. These materials are non-flammable and they would further reduce the amount of flammable organics in this type of construction. These materials are probably too expensive for use as back covers in superstrate modules where less expensive opaque materials can be used. Springborn Laboratories will investigate the burning characteristics of fluorocarbon films under conditions similar to those encountered in the UL-790 test and provide recommendations for their use, if appropriate.

- (b) Fire retardant compounds for use in polymers have been studied extensively and many highly effective combinations have been identified. Fire retardant chemistry is frequently achieved with a combination of ingredients that serve to (1) dilute the amount of combustible material, (2) release water of hydration to smother the flame, and (3) compound(s) that quench the combustion chemistry.

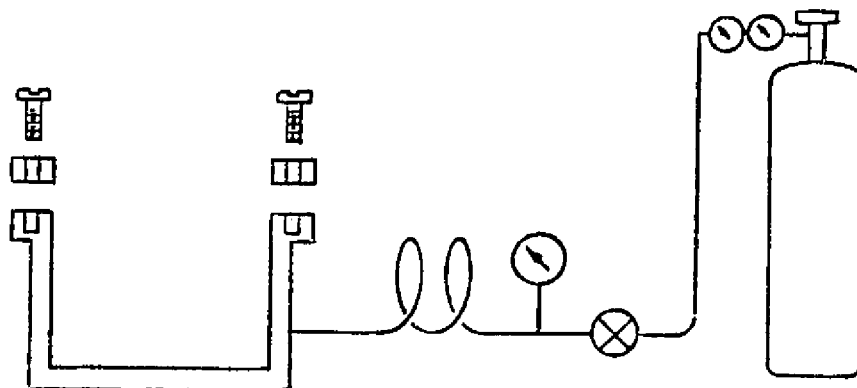
The most effective additives are the quencher variety. Typically, they consist of a combination of two or more chemicals that react upon heating to produce strong free radical terminators. These free radical reactive compounds are thought to intercept the activity of the hydroxyl radical that is predominant in combustion. The well known combination of antimony oxide and brominated phenyl compounds produces antimony tribromide fumes that serve this function.

- (c) The concept of containment is that flammable decomposition are not permitted to leave the module area and result in the ignition of other structures. Two approaches are employed here. The first is the containment of the depolymerized liquid pottant. There is suggestion from previous experimental work that the simple inclusion of Crangeglas (a non-woven glass cloth) serves to hold the fluid components in place and consequently prevent dripping of flammable material. The second

approach requires the containment of the combustible gases resulting from thermal decomposition and is not as easily implemented as the previous method. A high strength back cover material is proposed that has the ability to retain the flammable gases and prevent them from serving as an ignition source. Some experimental evidence suggests that this technique is effective and that a back cover film of high tensile strength at elevated temperatures is required. Recently, some modules prepared with DuPont's "Kapton" polyimide film were found to pass the UL-790 test procedure due to the fact that flammable gases were successfully prevented from escaping.⁽¹⁾ Researchers at Jet Propulsion Laboratories have also been successful in locating a commercial source of (proprietary) back cover material that passes the burning brand test.

B. Materials Testing

Due to the success of high strength occlusive back covers, experiments were conducted to measure their strengths under high temperature conditions and determine the criteria to which other candidate materials could be compared. This required the construction of a special piece of equipment which is diagrammed as follows:



(1) R.S. Sugimura, D. H. Otth, R.G. Ross "Development and Testing of Advanced Fire-Resistant Photovoltaic Modules", Proceedings: Institute of Environmental Sciences, 31st Annual Meeting, April 29th, 1985

This apparatus is a high temperature burst cell in which the rupture strength of candidate films may be determined. In use, the candidate film is clamped over the top of the chamber and apparatus is then placed in a circulating air oven and permitted to come to temperature. The chamber is then pressurized and the pressure required to burst the film is recorded. Two test procedures are under consideration: a) short term testing in which the film is brought to its ultimate burst pressure over a period of perhaps a few minutes, and b) pressure endurance testing, in which the time to burst at a fixed pressure is measured. Each may provide useful information related to the durability of the candidate under actual fire conditions.

The initial tests conducted with this apparatus were done with the Kapton cover passing class "B" burning brand test and two other candidates. The results are shown in the following table:

<u>High Temperature Burst Test</u>				
Temperature, °F (b)	300	400	500	600
Temperature, °C	149	204	260	315

<u>Material</u>	<u>Burst Point, psi</u>			
Kapton 4 mil	> 50	40	30	20
302 Stainless, 2 mil	> 50	>50	>50	>50
Tedlar 200BS30WH	< 5	<<5 ^(a)	J	0

(a) The Tedlar film chars rapidly at this temperature and ruptures at much less than 5 psi of applied pressure.

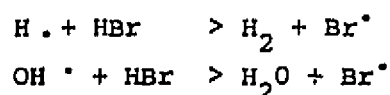
(b) These temperatures were selected on the basis of temperatures on the back of a module during a class "B" brand burn test.

As expected, films such as stainless steel and Kapton retain very high burst strengths over the range of temperatures selected. A white pigment-graded grade of Tedlar (2 mil thickness) was attempted, however the film degraded rapidly at the lowest (149°C) temperature and lost virtually all its strength. This method should be useful for comparative evaluations of candidate fire retardant back cover films as they are discovered.

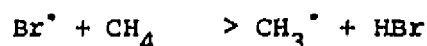
The use of fire retardant additives to lower the flammability of plastic materials is common practice. There are three general ways to render a polymer less flammable: inhibit flame reactions, retard condensed phase reactions, and slowdown the heat and mass transfer between the two regions.

By far, the most important flame retardants are the organic halides

A mechanism which accounts for most of the effect, involves replacement of the radical chain carriers with the less reactive halogen atoms:



The halogen radical produced slows down the propagation and chain branching reactions, reducing the overall radical concentrations. This is especially true in the relatively cool part of the flame, where the differences in reactivity are greatest. The leading edge of the flame is thus most susceptible to inhibition. When the halogen does react, it regenerates HX for further inhibition:



The inorganic halogen compounds are almost always used with synergists that greatly improve their effectiveness. The best known and most effective synergist is antimony oxide, which is known to generate the intermediate compound SbBr_3 under high temperature conditions that serves as a potent free-radical terminator.

Additive formulations to the EVA have been developed to provide fire retardancy to the back layer behind the cells. These formulations are based on well documented compositions known to be effective in polyolefins. The formulations are as follows:

V-6 .

Trial Fire Retardant EVA Formulations

No. 19510

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F*</u>	<u>G*</u>
Elvax 150	100	100	100	100	100		
TBEC	1.5	1.5	1.5	1.5	1.5		
Antimony Oxide	4.0	4.0	5.0	3.0	7.0		
Decabromodi- phenyl Oxide	12.0	12.0	15.0	15.0	20.0	"C" w/5 layers glass	"E" w/5 layers glass
Aluminum Trihydrate	30.0	20.0	50.0	50.0	75.0		
Calcium Sulphate	--	10.0	--	--	--		
Zinc Borate	--	--	--	9.0	--		
<u>UL94 Data</u>							
Burn Time, sec. (1st)	0	6.7	3.44	2.0	0	0	0
Dripping?	yes	yes	yes	yes	no	no	no
UL94 rating	V-2	NR	V-2	NR	V-1	NR**	V-0
<u>ASTM D-2863</u>							
Oxygen Index, %	--	--	--	--	--	--	30%

* Craneglas 230 (3 ml) used as non-woven glass mat filler by compression molding.

** Failed second ignition test.

The initial screening tests used for fire retardant formulations is the UL-94 test developed by Underwriters Laboratories for plastics materials used in electrical devices and appliances. It consists of exposing specimens to two successive, 10-second ignitions from a 3/4-inch Bunsen gas-burner flame. Specimens are then classified according to the time it takes for the flame to extinguish and the length of time any "afterglow" persists. Results are rated in three categories: V-0, extinguishment time 0 to 5 seconds, afterglow time 0 to 30 seconds, no flaming drips; V-1, extinguishment time 6 to 25 seconds, afterglow time 0 to 60 seconds, no flaming drips; and V-2, extinguishment time 0 to 25 seconds, afterglow time 0 to 60 seconds, flaming drips permitted.

Of these first-cut formulations only one passed the UL-94 test with a V-0 rating (self extinguishing in vertical position). This compound (19510-G) consisted of EVA with a 50% by weight loading of fire retardant additives and compression molded with non-woven glass cloth to prevent dripping. This resulted in a smooth white flexible sheet easily usable back layer of pottant in a module. This composition was further evaluated by ASTM D-2863 Limiting Oxygen Index. This test determines the percent of oxygen required to sustain burning of the test specimen and is widely used throughout the plastics industry. The results for this compound indicate a Limiting Oxygen Index of 30%, a value approximately equal to silicone rubber. This value is fairly high for a polyolefin and is an encouraging sign that fire retardant EVA formulations may further add to decrease the overall flammability of solar modules. For comparison Limiting Oxygen Index Values for commercial polymers are given as follows:

<u>Polymer</u>	<u>Oxygen Index, %</u>
Polyethylene	17.4
EVA	18.0
Polystyrene	18.1
Polycarbonate	27
Silicone Rubber	30-32
Polyvinyl Chloride	45-58
Carbon (Electrode)	63
Teflon (PTFE)	95

VI. DIELECTRIC PROPERTIES

Potential, outer cover films, back cover films and other components used in the construction of photovoltaic modules must perform a variety of functions, one of which is electrical isolation. In addition to providing a shock hazard, a short may also result in damage to the rest of the module from arcing or ignition of the encapsulation. Encapsulation materials must then be able to retain acceptable levels of insulation in order to (a) prevent direct shorting of electrical components, (b) prevent stray currents that may result in electrocorrosion, and (c) provide electrical isolation for safety reasons.

In order to insure reliability it is necessary to determine, not only the dielectric strength and required thickness for adequate insulation, but also the variation of this insulation value with aging and environmental exposure.

A DC power supply was purchased for these measurements^a and was equipped for adjustable rate of rise, adjustable overload current and a "memory" meter to record the voltage at breakdown. A special test jig was prepared from acrylic sheets separated by ceramic spacers with a platform of acrylic in the center to support the films under test. Two electrodes, one upper and one lower, were mounted in the acrylic sheets and wired to the power supply with high tension wire. The electrodes were made from 1/4 inch round brass rod with polished spherical (0.125" radius) tips. A plot of the DC breakdown voltage, V in volts versus thickness (in mils), was found to be linear and the slope of the line is considered the intrinsic dielectric strength in volts/mil.^b

a. 830B High Voltage Power Supply, Hipotronics, Inc., Brewster, N.Y.
Voltage range: 500 to 32,000 v. Rise rate: 100 v/sec. to 1.5 Kv/sec;
DC ripple 0.5% of output.

b. It must be noted that DC behavior is quite different than AC behavior. In AC dielectric testing the average dielectric strength (volts/mil) increases with decreasing thickness and is proportional to the square root of the thickness. Only plots of the log of the dielectric strength versus the log of the thickness are linear, and have a slope of roughly -0.5.

VI-2

Films in the ranges of approximately 2 to 8 mils of thickness were prepared and many trials of measuring the breakdown voltage were performed. When an adequate supply of films and thicknesses were obtained, twenty carefully controlled measurements were made of DC breakdown voltage at 500 v/sec rate of rise. The measurements are recorded and analyzed in the tables in the appendix, pages 19 and 20. Statistical analysis of the data gave the following values:

Slope = 3.48 KvDC/mil

Intercept + 1.03 KvDC ($t=0$)

Correlation Coefficient = 0.939

The correlation coefficient being close to 1 indicates a very close fit of the points to a straight line relationship, in which the slope of the line is found to be 3,480 volt/mil. This may be considered to be the DC intrinsic dielectric strength of EVA. A curious result of this experiment is that the intercept (thickness = 0) has a value of 1,030 volts instead of passing through the origin, as would be expected. Apart from the possibility of measurement errors, this observation may result from some other phenomenon such as surface charging or the presence of a forward breakdown threshold voltage, as is found for semi conductor junctions.

The apparatus and measurement techniques for determining the intrinsic dielectric strength in EVA and other polymers has been developed and the results appear to be accurate and reproducible. The next task will be to determine how this essential property varies during aging and assess the effect on long term performance of the module.

Retesting of aged specimens will be used to determine the effects of single aging variables on the intrinsic dielectric property and variations in the constants appearing in the above equation. Changes in the intrinsic dielectric property with respect to the thermal aging, hydrolytic aging, moisture absorption, light exposure and the incorporation of stabilizers and additives will be determined.

One of the other system stresses is the presence of electrical potential itself. The continual presence of an applied voltage may result in the gradual onset of dielectric breakdown mechanisms and may result in a "stress endurance" curve. Springborn Laboratories will plot this endurance curve by measuring the time to failure at a variety of stress levels. This data may then be plotted as log time to failure as a function of stress level, and may further be used to determine safe operating voltages for the service life of the module. A voltage level may also result from this experiment below which no breakdown occurs at all.

In actual operating conditions, the encapsulation components will be exposed to multiple stresses simultaneously. A special test chamber will be constructed to permit the dielectric test measurements to be performed with combinations of heat, atmosphere, humidity and voltage stress. These experiments should provide relevant information concerning (a) the intrinsic dielectric strength of candidate encapsulation materials, (b) determine which aging stress has the greatest effect on the insulation performance of a given material, (c) determine what combinations of stresses result in significant reductions in performance, and (d) provide information that may be used to guide engineering decisions concerning materials selection and dimensions.

VII. ANTI-SOILING TREATMENTS

The power output of photovoltaic modules is reduced by the accumulation of soil on the surface. The loss is due to shadowing of the cell, and losses of several percent may result. To minimize performance losses caused by soiling, photovoltaic modules not only should be deployed in low-soiling geographical areas, but also should have surfaces or surfacing materials with low affinity for soil retention, maximum susceptibility to natural removal by winds, rain, and snow; and should be readily cleanable by inexpensive maintenance techniques.

The theoretical aspects of soiling have been addressed in documents by the Jet Propulsion Laboratory.^(1,2,3) The basic findings of these studies show that the rate of soil accumulation in the same geographical area is material independent and that rainfall functions as a natural cleaning agent. The effectiveness of the cleaning effect of the rain is material dependent, however.

Based on the postulated mechanisms for soil retention on surfaces, certain characteristics of low-soiling surfaces may be assumed. They are, (a) hard, (b) smooth, (c) low in surface energy, (d) chemically clean of water soluble salts, and (e) chemically clean of sticky materials. It is possible that cost effective coatings having these properties may exist and be applied to solar module surfaces. This may result in low maintenance costs and preserve the effective generation of power from these modules.

1. Cuddihy, E. F., "Encapsulation Materials Status to December 1979" FSA Project Task Report 5101-144, Jet Propulsion Laboratory, Pasadena, CA January 15, 1980.
2. Hoffman, A. R., and Maag, C.R., "Airborne Particulate Soiling of Terrestrial Photovoltaic Modules and Cover Materials", Proceedings of the Institute of Environmental Sciences, May 11-14, 1980; Philadelphia, PA.
3. Cuddihy, E.F., and Willis, P.B., "Antisoiling Technology: Theories of Surface Soiling and Performance of Antisoiling Surface Coatings" FSA Project Report 5101-251, Jet Propulsion Laboratory, Pasadena, CA., November 1984

VII-2

Over the past few years Springborn Laboratories has evaluated the effectiveness of low surface energy treatments applied to candidate outer cover materials for use in solar modules. These candidate materials currently consist of low-iron glass, Tedlar fluorocarbon film (100BG30UT, DuPont) and a biaxially-oriented acrylic film (Acrylar; product X-22417, 3M Corp.). These materials are all relatively hard, smooth and free of water soluble residues. Experiments were conducted to determine if an improvement in soiling resistance could be obtained by the application of low surface energy treatments.

A survey of coating materials showed that very few commercial materials exist that could be useful for this purpose and that some experimental compounds had to be synthesized.

The anti-soiling experiments initially used seven treatments that included fluorocarbons, acrylics and silicone-based materials. After the first year of exposure it became clear that a number of candidates were ineffective and were consequently discontinued. Four treatments were continued in order to assess the long term performance in an outdoor soiling environment, as follows:

1. L-1668, an experimental fluorochemical silane produced by 3M Corporation that is used to impart water and oil repellency to glass surfaces. This material is not yet commercial.
2. L-1668 following treatment of the surface with ozone activation (for the organic films only).
3. Dow Corning E-3820-103B, and experimental treatment consisting of perfluorodecanoic acid coupled to a silane (Z-6020). This compound is not commercially available, but is easily prepared.
4. The E-3820-103B following surface treatment with ozone to create active sites on the organic polymer films.

These candidates consist of two surface coatings, but four treatments. Each coating is applied with and without surface treatment with ozone in order to activate bonding chemistry at the surface and enhance adhesion. No ozone treatment is used with the glass because surface activation is not required in this case.

These coatings/treatments were applied to each of the three candidate outer surfaces using the recommended application technique. The organic film materials Tedlar and Acrylar were supported by a piece of glass on the underside, and attached with a colorless and ultraviolet stable pressure sensitive adhesive. The completed test coupons were then mounted in outdoor racks on the roof of Springborn Laboratories' facilities in Enfield, Connecticut. Evaluation is performed monthly and a record of rainfall is also kept in order to correlate soiling effects with precipitation.

The degree of soiling on the completed specimens was measured by power transmission using a specially designed standard cell device. This instrument measures the drop in short circuit current, I_{SC} , when the soiling specimen is placed between the standard cell and the light source. This value is then compared to control and the percent decrease calculated.

The results of 46 months of outdoor exposure are shown graphically in pages 21 through 23 of the appendix. Only the best treatment and the control values are plotted, for clarity. The data reveals that fluctuating power transmissions are found for all specimens. The degree of loss varies according to the type of surface treatment and the particular month of exposure.

Sunadex glass, and the treatments applied to it, gave specimens with the best overall inherent soil resistance. The control, and most of the coated specimens, followed the same pattern of rising and falling simultaneously throughout the exposure period in agreement with the amount of rainfall. The winter months showed a dramatic decrease in power in all cases. A constant differential was found between the control measurements and the most effective coating, as may be seen in the figure, page A-21.

The best overall coating for Sunadex is found to be the compound designated E-3820 and gives reductions in I_{SC} that are .5 to 1% higher than the untreated control specimen. These reductions are consistent throughout the exposure period until about the 40th month, after which the untreated control begins to show better transmission than any of the treated specimens. At the 46 month measurement point the final values were:

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Sunadex, 46 Months

Control	+0.8%
L-1668	-1.3%
E-3820	-0.7%

The greatest improvement in anti-soiling performance was found when candidate treatments were applied to the organic outer cover films. The Acrylar acrylic films normally soil very badly. Throughout the 46 month exposure period the Acrylar control measurements showed I_{sc} losses in the order of 7% to 12%. All the treatments applied to Acrylar gave significantly improved performance. The values at the 46 month point were:

Acrylar, 46 Months

Control	-9.0%
L-1668	-5.3%
Ozone, then L-1668	-3.3%
E-3820	-6.5%
Ozone, then E-3820	-1.9%

The best treatment is clearly the E-3820 following ozone activation of the film surface. The improvement is dramatic, as is shown in the graph on page A-22. The improvement in retention of I_{sc} values is very consistent and in the order of 5% to 7% throughout the entire exposure period. Additionally, treatment with this compound keeps the transmission loss through Acrylar at a very tolerable 2% to 4%.

The third, and last, candidate outer surface to be investigated was Tedlar (100BG30UT), a transparent UV absorbing film of poly(vinyl fluoride) manufactured by DuPont. As with the Acrylar film, this material was mounted on glass squares with a pressure sensitive acrylic adhesive and deployed with the usual series of coatings/treatments. The control degraded steadily in power throughout reaching almost 9% loss in the tenth month and slowly recovered to a 4% to 6% loss that varied over the exposure period.

VII-5

For Tedlar 100BG3OUT, the best treatment was found to be the E-3820 perfluoro-decanoic acid-based adduct and appeared to work the best when the Tedlar film was not pretreated with ozone. At the end of the 46 month exposure period the following values were found:

Tedlar, 46 Months

Control	-4.7%
L-1668	-3.4%
Ozone, then L-1668	-3.4%
E-3820	-2.6%
Ozone, then E-3820	-5.9%

Treatment with plain E-3820 solution gave values consistently 2% to 5% better than those of the control.

Examination of the data trends in soiling show that the low points, in the tenth and twentieth months, correspond to periods of little rainfall. These are the winter months in Enfield where there is almost no rain and the precipitation occurs as snow, which is not found to have any cleaning action on the specimen surface. All the specimens begin to regain their transmission and I_{sc} values as the Spring rains occur in the months of April through June. The rainfall data, which correlates well with the fluctuations of soiling data, is given in page A-21.

In summary, low surface energy treatments, based on fluorosilane chemistry, appear to be effective in retarding the accumulation of soil on candidate outer surfaces of interest in module construction. The most successful treatments identified to date are: for Sunadex and Tedlar, E-3820, for Acrylar, ozone pretreatment followed by E-3820. This surface coating is based on expensive fluorochemicals, however it should prove to be cost-effective due to the extremely small amount that is applied to the surface. This coating appears to be effective where there are weather conditions that result in "natural cleaning" of the surface, and it seems that a certain amount of rain is required to keep the light transmission high.

VIII. OUTER COVER MATERIALS

Due to the relatively high cost of glass (appx. $\$0.90/\text{ft}^2$) and the low cost of structural materials such as steel ($\$0.25/\text{ft}^2$) and wood products ($\$0.15/\text{ft}^2$), substrate designs offer a potential cost advantage in the construction of PV modules. With the use of wood or mild steel and additional cost component will be required for environmental protection, however the composite cost is still imagined to be considerably lower than that of a glass surfaced superstrate module. In substrate designs, the cell string is supported from the underside, leaving the cell string and pottant exposed on the outer sunlit side.

Soft elastomeric materials must be used for pottants in order to prevent cracking of the silicon cells due to stresses resulting from thermal expansion differences. Soft materials are prone to soiling and dust retention which reduces the light transmission and impairs the module efficiency. Hard coatings are, therefore, desirable to avoid this problem. Additionally, the function of UV screening is desirable in order to reduce the effects of photolytic degradation and provide the maximum useful lifetime for the pottant and other components.

The properties of an idealized outer cover may be stated as follows:

- (1) high optical transparency;
- (2) compatible refractive index properties that favor optical coupling;
- (3) compatibility with either the pottant or a suitable primer to insure a high reliability bond that will last the useful lifetime of the module;
- (4) inherent weatherability;
- (5) ultraviolet light screening properties to protect the underlying pottant;
- (6) anti-reflective properties to increase the total light transmission;
- (7) resistance to prevent loss of material or sufficient haze to impair the transmission characteristics.

In accordance with these requirements, Springborn Laboratories has continued to evaluate transparent weatherable organic films and coatings that have the ability to screen out UV light. Many of the candidate pottant compounds do not appear to need this UV protection however, and seem to be remarkably resistant to photodegradation. The RS/4 sunlamp exposure, normally regarded as severe

VIII-2

In accordance with these requirements, Springborn Laboratories has continued to evaluate transparent weatherable organic films and coatings that have the ability to screen out UV light. Many of the candidate pottant compounds do not appear to need this UV protection however, and seem to be remarkably resistant to photodegradation. The RS/4 sunlamp exposure, normally regarded as severe in the polymer industry, results in failure of unprotected EVA 9918 only after 40,000 hours. This is a remarkably long time and indicates a high resistance to UV degradation. If the photolytic effect is not considered to be a problem then the investigation of suitable outer covers may now be expanded to include films that do not have UV screening properties. The appended table (no. 24) is a survey of commercially available non-screening outer cover films. The two most important factors are cost ($\$/\text{ft}^2/\text{mil}$) and the power transmission.

Two promising films are oriented Kynar (Pennwalt Corp.) and FEP (DuPont). Kynar is now being marketed as a transparent, weather-resistant film designed for solar energy application. This strong, tough, fatigue resistant film is particularly useful for solar collectors, solar stills, and greenhouse glazing. Kynar PVDF is exceptionally stable to ultraviolet radiation and its mechanical properties are maintained throughout many years of outdoor exposure. The manufacturer claims that oriented Kynar film on accelerated weathering to an equivalent of 16 to 28 years exposure, lost 2-5% of its original specular transmittance and showed only insignificant change in mechanical properties. Additionally, its lower refractive index than acrylics or Tedlar films should be an advantage in optical coupling to increase the transmitted light. The idea of optical coupling to improve the throughput of power is also a consideration. Light entering any combination of materials in which there is a discontinuity in the index of refraction will result in a partial reflection at the interface and consequent loss of transmitted energy. The degree of this reflection is the reflection coefficient, R.

VIII-3

For a given interface with index n_1 on one side and n_2 on the other, the reflection coefficient, R , can be expressed as:

$$R = \frac{(n_1 - n_2)^2}{(n_1 + n_2)^2}$$

R is reflection coefficient

n_1 is refractive index of medium 1

n_2 is refractive index of medium 2

For example, if medium 1 is glass (Index 1.5) and medium 2 is air (1.0), the reflection coefficient R =

$$R = \frac{(0.5)^2}{(2.5)^2} = 0.04 \text{ or } 4\%$$

For passage of light through a pane of glass, there will be a loss of about 4% on entering and another 4% on leaving. This value agrees well with experimental data and gives a glass/air interface a maximum transmission of 92%.

DuPont's FEP film (fluorinated ethylene/propylene copolymer) is another strong contender for the outer cover application. FEP is a flexible, compliant film with a slight bluish cast and demonstrated weatherability. FEP and related fluoropolymers have well over twenty years of actual outdoor exposure with absolutely no change in properties. This material is more expensive than Kynar, however its lower refractive index may improve the light throughput and cause it to be cost effective. Repeating the reflection calculation with FEP (refractive index = 1.34) gives a reflection coefficient of 2.16% per surface. This indicates that for free standing film an FEP/air interface has a transmission of 95.7%, an improvement of 3.7% over glass. This improvement in the use of available sunlight may well justify the use of a more expensive film.

Due to the potential for improved weatherability and power output with these films, these are being incorporated into the evaluation program as candidate outer cover materials and will be assessed for suitability in module applications.

IX. LOW TEMPERATURE ENCAPSULANTS

Amorphous and thin-film PV efforts are gaining momentum and have the potential for large scale commercialization. With this technology comes the need for a different type of encapsulation than has been required for single crystal PV devices. Due to the flexibility of thin film devices a wider range of polymers and processing techniques become available with the possibility of encapsulating the PV devices in tandem with production. The criteria being considered for the initial selection of thin film devices are:

1. Processable at temperatures at or less than 100°C^a.
2. Optically transparent after curing
3. Curable, the final composition must be resistant to thermal creep
4. Extrudable-thin films are desirable for processing
5. Flexible, but not necessarily very low in modulus
6. Weatherable and environmentally resistant

The following table indicates generic classes of polymer materials that may be suitable for this application:

<u>Material Class</u>	<u>Manufacturer</u>	<u>\$/lb</u>
Polyethylene (LDPE)	Many	.50 - .60
Ethylene/Vinyl Acetate	DuPont, USI	.60 - .80
Ethylene/Acrylic	Dow, Gulf	.80 - 1.00
Ionomer	DuPont	1.08 - 1.60
Aliphatic Urethane (Hydrocarbon, Polyamide Polyether, Acrylic)	Upjohn, Mobay, Wayandotte, Development Assoc.	1.70 - 2.50

(a) Experimental evidence suggests that the performance of amorphous silicone cells is damaged by heat and that temperatures as low as 130°C may impair power output. Ref: J. W. Lathrop, "Photovoltaic Cell Reliability Research" Clemson University, Clemson, South Carolina, September 1984.

These materials also offer the opportunity to explore other types of encapsulation methods than have been used before. Possibilities include film co-lamination, extrusion coating, roll coating and spray coating. Curing the polymer coating may be inherent to the chemistry of the polymer as with thermosets, or may require a peroxide additive to initiate the crosslinking reactions. Other possibilities include UV initiated systems (photo-initiation) and moisture cures as our found with some urethanes and certain silane modified olefins.

Springborn Laboratories Inc. will initiate a new materials investigation to identify commercially available materials suitable for this application.

SECTION BX. PROCESS SENSITIVITYA. Goals and Methodology

EVA is now becoming the standard encapsulation material for the fabrication of commercially produced PV modules and has superceded materials such as PVB and RTV type silicone rubbers due to the improvement in performance and the increased cost-effectiveness. The development of the advanced materials has been accompanied by the development of new and advanced processing technologies in which PV modules may be manufactured more easily, more controllably, and with the potential for high speed automation. The fabrication technology for the use of these new encapsulants involves the carefully controlled sequence of heating, vacuum, pressure and timing. The equipment used for this process is a double chambered vacuum bag laminator. This device, when properly used, results in modules of uniform quality and performance, and may be scaled to almost any commercial module size.

In addition to the EVA encapsulants that use this vacuum process, Springborn Laboratories has also identified two liquid encapsulation compounds that may be used by manufacturers who still desire to encapsulate with the liquid systems. Although these new liquid systems do not employ the use of the vacuum bag laminator, they still require a carefully controlled set of processing conditions to result in their successful use and consistent production of quality modules. It is the purpose of Phase II of this program to systematically investigate controlled variations in the encapsulant formulations and processing technologies, such that a sensitivity analysis of these variables results. This sensitivity analysis will provide data concerning the relative importance of each parameter and also a quantitation of each so that manufacturing yield probabilities may be assessed. In a systematic study, data will result indicating the formulation and processing "windows" from which acceptable levels of variation may be tolerated in industrial practice. The required data will be obtained experimentally and then fitted to a mathematical

Model for correlation. These correlations will hopefully permit the manufacturing yields to be determined and related to the set of independent variables.

This task is to be performed in a series of steps, each step providing both useful information to module fabricators and technical groundwork for succeeding steps. Overall, the goals of this task may be stated simply as:

- o understand the relationships between:
 - . formulation variables
 - . process variables
- o define conditions required for optimum performance
- o relate to failure/acceptability criteria
- o predict manufacturing yield
- o provide documentation to industry

The first step in accomplishing these goals is the enumeration of potentially important independent variables. Two types of independent variables must be considered: material variables and processing variables. Material variables consist of (for example):

- (1) type of pottant: EVA, EMA, Polyurethane,
- (2) type of cover film: Tedlar, Acrylar, etc.,
- (3) type of adhesive/primer formulation and application technique,
- (4) formulation variables, such as type and amount of :
 - (a) curing agents (peroxides)
 - (b) antioxidants
 - (c) ultraviolet screeners
 - (d) ultraviolet stabilizers
- (5) storage conditions: time, temperature, humidity, and air exposure.

These material variables interact with the set of processing variables to result in modules of a certain quality and manufacturing yield. Some of the processing variables that are of consideration are:

- (1) ambient conditions:
 - . temperature
 - . humidity
 - . barometric pressure
- (2) vacuum pressure (initial) and time of evacuation
- (3) temperature - rate of rise
- (4) temperature - ultimate
- (5) dwell time, at temperature
- (6) rate of cooling
- (7) time/temperature/pressure interrelationship,

and for liquid casting systems, such as the polyurethane syrup, the above variables apply, plus:

- o 2 component mix time
- o degassing pressure
- o pump and fill times
- o mix uniformity
- o gel time

The interaction of these two sets of independant variables give rise to a set of dependant variables (resultants) that correspond to the acceptability or lack of acceptability of the resulting module. What constitutes acceptance or rejection of the module depends on the pre-established criteria of performance. This requires that the type of failure be identified and the level of acceptance specified. For example, cell breakage constitutes a failure type, but there also exists a function describing the probability of failure. What level is designated as acceptable, 1% or 10^{-5} %?

The dependant (or performance) variables by which the module quality is judged also fall into two types; continuous and discrete. Continuous variables are those in which the value of the variable may assume any value over a continuous range. For example; gel content which may vary from 0% to 100%. Discrete variables are those that assume one of two specific values. For example cell breakage, cells are either fractured or not (pass/fail). The presence of two data types also complicates the analysis and may require that two types of treatment be used. Examples of the dependant variable types to be considered are:

<u>Encapsulation Component</u>	<u>Dependant Variable</u>	<u>Test Method</u>	<u>Variable Type</u>
Pottant	Cure	Gel content	Continuous
	Trapped bubbles	Visual	Discrete
	Discoloration	Spectroscopy	Continuous
Solar Cells	Fracture	Visual	Discrete
	Interconnect pull	Resistance	Discrete
	Registration	Visual	Continuous
Cover Films	Tears/puncture	Visual	Discrete
	Warping/shrinkage	Visual	Continuous
Glass	Fracture	Visual	Discrete
Adhesion	Bond strength	Peel test	Continuous
	Bond durability	Water soak	Discrete

The relationship between the independant and dependant variables must be determined in a qualitative and quantitative manner. The term "qualitative" is used here to indicate the criteria of acceptance (or failure) that is assigned to each dependant variable, and the term "quantitative" implies the magnitude of the effect.

Initial experiments will explore the effects of a single independent variable on the set of dependent variables and determine the boundaries of the "window" on either side of which is a failure condition. In instances where two or more variables operate together the well known factorial design experiments will be used.

In this type of experiment, the effects of K factors, or independent variables, are measured at two or more levels. Using simple vectors or least squares linear technique, the effect that a processing or formulation variable has on a dependent variable may be assessed.

This experimental technique is known to have the following advantages:

- (1) a lot of information is gained from a relatively small number of experiments, in which the number of experiments is equal to n^K , where n is the number of levels selected and K is the number of factors, or independent variables,
- (2) it may be used with both continuous and discrete data types,
- (3) the effects of single variables and combined variables may be quantitated and ranked according to the magnitude of the effect,
- (4) regions where the factor effects are observable may be determined and permit the selection of experimental conditions that may be subsequently used for the modeling of probability functions using normal distribution curves.

Where probability functions of failure can be calculated, manufacturing yield may also be calculated. This permits the quantitative assessment of the effect of a manufacturing variable on the success of the overall operation. A flow chart of the anticipated experimental procedure is attached in the appendix, page A25.

B. Experimental Results

One of the first variables investigated was that of changing the peroxide content of EVA and determining the effect on cure. This investigation was conducted particularly because of a suspicion that peroxide may be evaporating from the EVA sheet. Peroxide concentrations of 0.5%, 0.75%, 1.0% and 1.5% were used and both Lupersol-101 cured EVA (9918 and Lupersol-TBEC cured (15295) materials were prepared. Cure temperatures from 120°C to 160°C at dwell times of 5 to 30 minutes were used to cure plaques for gel content analysis. The results are tabulated on pages 26 and 27 in the appendix. For Lupersol-101 cured compositions, the

combinations of time and temperature that result in acceptable levels of cure are found to diminish as the level of peroxide is decreased. In decreasing the peroxide from 1.5 phr^(a) to 0.5 phr, the cure time must be doubled, or the temperature raised by 10°C, in order to obtain an approximately equivalent gel content (in the temperature ranges where cure occurs). Diminished peroxide content, even from 1.5 phr to 1.0 phr, is seen to have a fairly strong impact on the resulting gel contents and serves to narrow the processing latitude. The TBEC cured EVA appears to be much less sensitive to variations in peroxide concentration. Decreases in the cure performance are observable, however they are much more tolerable. Decreasing the peroxide from 1.5 phr to 0.5 phr basically stops the cure process from occurring at 130°C, but has little effect on the cure schedules at higher temperatures. In conclusion, TBEC cured EVAs are much less sensitive to peroxide concentrations than the Lupersol-101 equivalents in which processing latitudes must be more carefully controlled.

Studies have been conducted to determine the shelf life and required storage conditions for EVA film products. When freshly prepared and stored in a closed plastic bag, Springborn's EVA lamination films appear to be stable for an indefinitely long period of time. In general, a cool dry location in which the film is not exposed to sunlight is recommended. EVA becomes sensitive to changes in its cure properties after it has been removed from its protective plastic bag. Experiments were conducted to determine the gel content (degree of cure) versus open exposure of EVA sheet to air. Two cure temperatures, 140° and 150°, were used. The results are tabulated, as follows:

(a) phr; parts per hundred parts resin.

X-7

	<u>EVA NUMBER</u>	
	<u>A9918</u>	<u>15295</u>
Cure	150°/20 min	150°/5 min
Conditions:	140°/20 min	140°/5 min
<u>Air Exposure</u>	<u>Gel Contents</u>	
0 Hours	80%	93%
	71%	91%
24 Hours	82%	85%
	64%	91%
48 Hours	78%	81%
	0%	72%
72 Hours	70%	83%
	0%	82%
168 Hours (one week)	0%	70%
	0%	0%

These results indicate that formula A9918 is rapidly affected by exposure to the open air. Exposure of the fast cure formula, EVA 15295, is much less detrimental, however a gradual decrease in the ability to cure may still be observed.

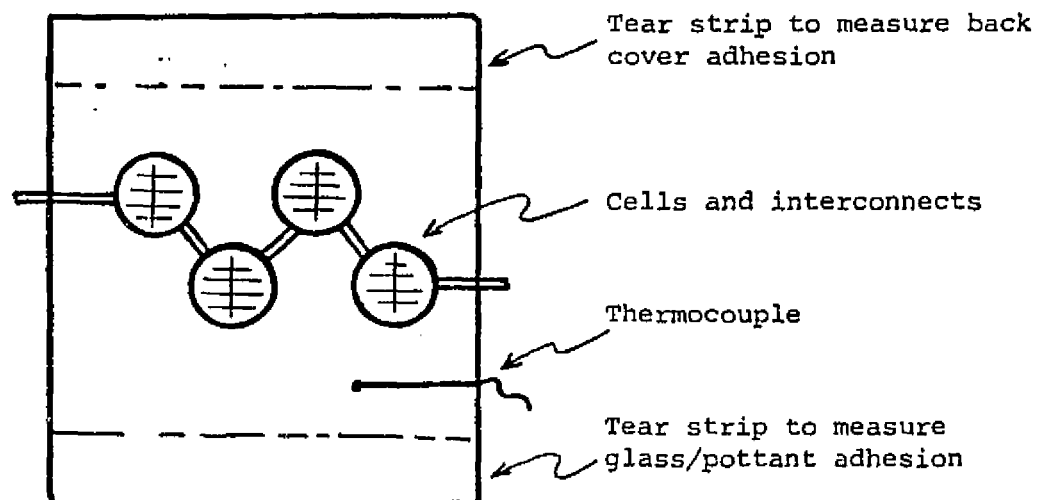
Specific Recommendations

1. Keep all EVA film products wrapped in a closed plastic bag during storage and at the end of each day of module production.
2. Store the rolls of EVA in a cool, dry location out of sunlight.
3. At the beginning of each day's fabrication run, discard the first wrap of EVA film and use the underlying plies for module production.

C. Experimental Process Laminator

An experimental laminator is under construction with the ability to fabricate small modules of 11.5" x 15" size. This laminator is equipped with rapid response heaters and is entirely microprocessor-controlled. Ultimate temperatures, rates of rise, dwell time and cool-down rates may all be specified under software control. This permits variations in process conditions to be changed easily and, in addition, the controller may activate other functions such as electrically actuated valves. With this equipment a process lamination process cycle may be completely specified.

Each lamination run is monitored by a thermocouple placed within the module connected to a strip-chart recorder and the reproducibility of specified conditions has been found to be very good. Because of the large number of potentially significant variables, uniform data sets are required and a "universal test module" was designed for this purpose. This module has the following construction:



This module has been found to be ideal for the evaluation of process dependent variables and is evaluated for the following properties:

Pottant	Bubbles (visual) Gel Content, % Swell Index, % Discoloration (visual) Spectroscopy (%T)
Cells	Registration (visual) Fracture (visual) Continuity, ohms
Glass	Fracture (visual)
Cover Film	Edge Shrinkage, mm Tear/Puncture (visual) Indented/Rippled (visual)
Adhesion	Pottant/Glass lbs/in Pottant/Cover lbs/in

An example of a standard test evaluation form is included in the appendix, page 28. The results of these experiments will be used to discover the dominant failure modes encountered in materials and processing, and eventually define the processing "windows" required for the fabrication of modules of predictable quality. Additionally, these experiments will point out caveats for module manufacturers who use EVA, and permit the writing of a "trouble shooting" guide. A preliminary guide has already been prepared and appears as pages 29 and 30 in the appendix. This document will be continually up-dated as information on material and process quality control becomes available.

A P P E N D I X

MODULE EXPOSURE

Notebook Number: 16747-1 Test Site: Enfield, CT
 Exposure Condition: OPT-70°C Size: 5.5 x 9" 2-cell

Construction: Glass(11861)/EVA9918/C^UIs(68040)/EVA/T^Udlar 200BS30WH-68040

Test	Exposure, Hours	6,000	7,000	10,000	12,000	14,000
	Test Date	7/11/84	8/22/84	12/22/84	3/15/85	6/7/85
Cells	Rainfall, Inches					
	Condition					
	Voltage, V _{oc}					
Metals	Current, I _{sc}					
	Cell Metalization	1	1	1	1	
	Interconnects	1	1	1	1	
Encapsulation	at edge:	1	1	1	1	
	Internally:	1	1	1	1	
	Outer Cover	1	1	1	1	
Notes	Back Cover	1	1	1	1	
	Sealant					
	Gasket					
	Pottant	1	1	1	1	
	Pottant + Copper	1	A3	A4	A4	
	Pottant Delamination:	1	1	1	1	
	Cells + Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

MODULE EXPOSURENotebook Number: 16747-2 Test Site: Enfield, CTExposure Condition: OPT-70°C Size: 5 1/2" x 9" 2-cellConstruction: Glass(68040)/EVA16718A/Cells(68040)/EVA/Tedlar200PS30WH-68040

Test	Exposure, Hours	6,000	7,000	10,000	12,000	14,000
	Test Date	7/11/84	8/22/84	12/15/84	3/15/85	6/7/85
Cells	Rainfall, Inches					
	Condition					
	Voltage, V_{oc}					
Metals	Current, I_{sc}					
	Cell Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
Encapsulation	at edge:	1	1	1	1	
	internally:	1	1	1	1	
	Outer Cover	1	1	1	1	
Notes	Back Cover	1	1	1	1	
	Sealant					
	Gasket					
	Pottant	1	1	1	1	
	Pottant + Copper	1	1	1	1	
	Pottant Delamination:	1	1	1	1	
	Cells + Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

MODULE EXPOSURENotebook Number: 16747-3Test Site: Enfield, CTExposure Condition: OPT-70°CSize: 5 1/2" x 9" 2-cell

Construction:

Test	Exposure, Hours	6,000	7,000	10,000	12,000	14,000
	Test Date	7/11/84	8/22/84	12/22/84	3/15/85	6/7/85
Cells	Rainfall, Inches					
	Condition					
	Voltage, V_{oc}					
Metals	Current, I_{sc}					
	Cell Metalization	1	1	1	1	
	Interconnects	1	1	1	1	
	at edge:	1	1	1	1	
Encapsulation	internally:	1	1	1	1	
	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	
	Sealant	1	1	1	1	
	Gasket	1	1	1	1	
	Pottant	1	1	1	1	
	Pottant + Copper	1	1	1	1	
	Pottant Delamination:	1	1	1	1	
	Cells + Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	
Notes						

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

MODULE EXPOSURE

Notebook Number: 16747-4 Test Site: Enfield, CT
 Exposure Condition: OPT070°C Size: 5 1/2" x 9" 2-cell

Construction: Glass(11861)/EVA 14747/Cells(11861)/EVA/T*dlar200BS30WH-68040

Test	Exposure, Hours	6,000	7,000	10,000	12,000	14,000
	Test Date	7/11/84	8/22/84	12/22/84	3/15/85	6/7/85
	Rainfall, Inches					
Cells	Condition					
	Voltage, V _{oc}					
	Current, I _{sc}					
Metals	Cell Metalization	1	1	1	1	
	Interconnects	1	1	1	1	
	at edge:	1	1	1	1	
	internally:	1	1	1	1	
Encapsulation	Outer Cover	B	B	B	B	
	Back Cover	1	1	1	1	
	Sealant					
	Gasket					
	Pottant	1	1	1	1	
	Pottant + Copper	1	A2	A2	A2	
	Pottant Delamination:	1	1	1	1	
	Cells + Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	
Notes						

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

MODULE EXPOSURENotebook Number: 16747-1Test Site: Anfield, CTExposure Condition: OPT-90° CSize: 5 1/2" x 9" 2-c-11Construction: Glass(11861)/EVA 9918/C¹¹s(11861)/EVA/T^{cd}lar 200BS30WH-68040

Test	Exposure, Hours	6,000	7,000	10,000	12,000	14,000
	Test Date	7/11/84	8/22/84	12/22/84	3/15/85	6/7/85
Cells	Rainfall, Inches					
	Condition	2	2	2	2	2
	Voltage, V _{oc}					
Metals	Current, I _{sc}					
	Cell Metalization	1	1	1	1	1
	Interconnects	2	2	2	2	2
	at edge:	1	1	1	1	
	internally:	C2	C2	C2	C2	
Encapsulation	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	
	Sealant					
	Gasket					
	Pottant	A2	A2	A2	A ²	
	Pottant + Copper	A2 E3	A3 E3	A3 E3	A3 E3	
	Pottant Delamination:	1	1	1	1	
	Cells + Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
	Outer Cover	1	1	1	1	
Notes	Back Cover	1	D2	1	1	
			Small amount of edge delamination.			

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

MODULE EXPOSURE

Notebook Number: 16747-2 Test Site: Enfield, CT
 Exposure Condition: OPT-90° C Size: 5 1/2" x 9" 2-cell

Construction: Glass(68040)/EVA 16718A/cells(11861)/EVA/Tedlar200BS30WH-68040

Test	Exposure, Hours	6,000	7,000	10,000	12,000	14,000
	Test Date	7/11/84	8/22/84	12/22/84	3/15/85	6/7/85
Cells	Rainfall, Inches					
	Condition					
	Voltage, V_{oc}					
	Current, I_{sc}					
Metals	Cell Metalization	1	1	1	1	
	Interconnects	A2	A2	A2	A2	
	at edge:	1	1	1	1	
	internally:	C2	C2	C2	C2	
Encapsulation	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	
	Sealant	1	1	1	1	
	Gasket					
	Pottant	1	A2	A2	A2	
	Pottant + Copper	1	A2	A2	A2	
	Pottant Delamination:	1	1	1	1	
	Cells + Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	
Notes						

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

MODULE EXPOSURE

Notebook Number: 16747-3 Test Site: Enfield, CT
 Exposure Condition: OPT-90°C Size: 5 1/2" x 9" 2-cell

Construction: Glass(11861)/EMA 16717/Cells(11861)/Tedlar 200BS30WH-68040

Test	Exposure, Hours	6,000	7,000	10,000	12,000	14,000
	Test Date	7/11/84	8/22/84	12/22/84	3/15/85	6/7/85
Cells	Rainfall, Inches					
	Condition					
	Voltage, V _{oc}					
	Current, I _{sc}					
Metals	Cell Metalization	1	1	1	1	
	Interconnects	1	1	1	1	
	at edge:	1	1	1	1	
	internally:	1	1	1	1	
Encapsulation	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	
	Sealant					
	Gasket					
	Pottant	1	1	A2	A2	
	Pottant + Copper	1	1	1	A2	
	Pottant Delamination:	1	1	1	1	
	Cells + Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
	Outer Cover	1	1	1	1	
	Back Cover	1	1	1	1	
Notes						

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticeable
 4 = Moderate
 5 = Severe

MODULE EXPOSURE

Notebook Number: 16747-4 Test Site: Enfield, CT
 Exposure Condition: OPT-90°C Size: 5 1/2" x 9" 2-cell

Construction: Glass(11861)/EVA 14747/Cells(11861)/EVA/Tedlar20BS30WH-68040

Test	Exposure, Hours		6,000	7,000	10,000	12,000	14,000
	Test Date		7/11/84	8/22/84	12/22/84	3/15/85	6/7/85
Cells	Rainfall, Inches						
	Condition						
	Voltage, V _{oc}						
Metals	Current, I _{sc}						
	Cell Metallization		1	1	1	1	
	Interconnects		1	A3	A3	A3	
	at edge:		1	A3	1	1	
Encapsulation	internally:		1	1	1	1	
	Outer Cover		1	B	B	B	
	Back Cover		1	1	1	1	
	Sealant						
	Gasket						
	Pottant		1	A3	A3	A3	
	Pottant + Copper		A2	A4	A4	A4	
	Pottant Delamination:		1	1	1	1	
	Cells + Metallization		1	1	1	1	
	Interconnects		1	1	1	1	
	Outer Cover		1	1	1	1	
	Back Cover		1	1	1	1	
Notes							

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

MODULE EXPOSURE

Notebook Number: 16747-1 Test Site: Enfield, CTExposure Condition: OPT-105°C Size: 5 1/2" x 9" 2-cellConstruction: Glass/11861/ EVA 9918/Cells -11861/EVA/Tedlar 200 BS30WH-68040 adhesive

Test	Exposure, Hours	6,000	7,000	10,000	12,000	14,000
	Test Date	7/11/84	8/22/84	12/22/84	3/15/85	6/7/85
Cells	Rainfall, Inches					
	Condition					
	Voltage, V_{oc}					
Metals	Current, I_{sc}					
	Cell Metalization	1	1	1	1	
	Interconnects	1	1	1	1	
Encapsulation	at edge:	1	1	1	1	
	internally:	1	1	1	1	
	Outer Cover	B	B	B	B	
Notes	Back Cover	1	1	1		
	Sealant					
	Gasket					
	Pottant	A4	A4 E5 D3	A4 E5 D3	A4 E5 D3	
	Pottant + Copper	A5 E5	A5 E5	A5 E5	A5 E5	
	Pottant Delamination:	D3	D3	D3	D3	
	Cells + Metallization	A2	A2	A2	A2	
	Interconnects	A2	A2	A2	A2	
	Outer Cover	E5	E5	E5	E5	
	Back Cover	E5 D5	E5 D5	E5 D5	E5 D5	
Notes				Pottant has leaked out of back of middle cells still OK		

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

MODULE EXPOSURE

Notebook Number: 16747-2 Test Site: Enfield, CT
 Exposure Condition: OPT-105°C Size: 5 1/2" x 9" 2-c-11

Construction: Glass (11861)/EVA 16718A/ c¹¹11s(11861)/EVA/T^{cd}lar 200BS30WH-
 68040 Adhesive

Test	Exposure, Hours	6,000	7,000	10,000	12,000	14,600
	Test Date	7/11/84	8/22/84	12/24/84	3/15/85	6/7/85
Cells	Rainfall, Inches					
	Condition	1	1	1	1	
	Voltage, V _{oc}					
Metals	Current, I _{sc}					
	Cell Metalization	1	1	1	1	
	Interconnects	1	1	1	1	
	at edge:	1	1	1	1	
	Internally:	1	1	1	1	
Encapsulation	Outer Cover	B	B	B	B	
	Back Cover	1	1	1	1	
	Sealant					
	Gasket					
	Pottant	A2	A2	A2	A2	
	Pottant + Copper	A4	A5	A5	A5	
	Pottant Delamination:	1	1	1	1	
	Cells + Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
	Outer Cover	1	1	D2	D2	
Notes	Back Cover	1	1	1	1	

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

MODULE EXPOSURE

Notebook Number: 16747-3 Test Site: Enfield, CT
 Exposure Condition: OPT-105°C Size: 5 1/2" x 9" 2-cell

Construction: Glass(11861)/EMA 16717/cells(11861)/EMA/Tedlar 200BS30WH-
-68040 adhesive

Test	Exposure, Hours					
	6,000	7,000	10,000	12,000	14,000	
Cells	Test Date					
	7/11/84	8/22/84	12/22/84	3/15/85	6/7/85	
Cells	Rainfall, Inches					
Cells	Condition					
Cells	Voltage, V _{oc}					
Cells	Current, I _{sc}					
Metals	Cell Metallization					
	1	1	1	1		
Metals	Interconnects					
	1	1	1	1		
Metals	at edge:					
	1	1	1	1		
Metals	internally:					
	1	1	1	1		
Encapsulation	Outer Cover					
	1	1	1	B		
Encapsulation	Back Cover					
	1	1	1	1		
Encapsulation	Sealant					
Encapsulation	Gasket					
Encapsulation	Pottant					
	A2	A4	A4	A4		
Encapsulation	Pottant + Copper					
	A4	A5	A5	A5		
Encapsulation	Pottant Delamination:					
	D3	D3	D3	D3		
Encapsulation	Cells + Metallization					
	1	1	1	1		
Encapsulation	Interconnects					
	1	1	1	1		
Encapsulation	Outer Cover					
	1	1	1	1		
Encapsulation	Back Cover					
	1	1	1	1		
Notes		Pottant beginning to turn light brown color.				

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticeable
 4 = Moderate
 5 = Severe

MODULE EXPOSURE

Notebook Number: 16747-4 Test Site: Enfield, CT
 Exposure Condition: OPT-105°C Size: 5 1/2" x 9" 2-cell

Construction: Glass(11861)/EVA 14747/Cells(11861)/EVA/Tedlar 200BS30WH-
- 68040 adhesive

Test	Exposure, Hours	6,000	7,000	10,000	12,000	15,000
	Test Date	7/11/84	8/22/84	12/22/84	3/15/85	6/7/85
Cells	Rainfall, Inches					
	Condition					
	Voltage, V _{oc}					
Metals	Current, I _{sc}					
	Cell Metalization	1	1	1	1	1
	Interconnects	C3	C3	C3	C3	
Encapsulation	at edge:	A3	A3	A3	A3	
	internally:	C3	C3	C3	C3	
	Outer Cover	B	B	B	B	
Notes	Back Cover	1	D2	D2	D2	
	Sealant					
	Gasket					
Notes	Pottant	A4	A4	A4	A4	
	Pottant + Copper	A3	A5	A5	A5	
	Pottant Delamination:	1	1	1	1	
Notes	Cells + Metallization	1	1	1	1	
	Interconnects	1	1	1	1	
	Outer Cover	1	1	1	1	
Notes	Back Cover	1	1	1	1	

A = Discoloration
 B = Broken/fractured
 C = Corrosion
 D = Delamination
 E = Flow/melt

1 = No change
 2 = Slight Change
 3 = Noticable
 4 = Moderate
 5 = Severe

HYDROTHERMAL AGING - GLASS BEAD FILLED
POLYMER SPECIMENS

TEMP. 40 °C

SPECIMEN NO.	PROPERTY *	CONTROL	100 HRS	500 HRS	2,000 HRS	5,000 HRS
18181-A EVA, W/O Primer	MOD	2,830	1.6×10^3	1.7×10^3	8.3×10^2	
	UT	1,380	1,295	1,230	1,210	
	UE, %	600	600	570	510	-
	Δ Wt, %	---	+0.15%	+18.9%	+51%	
	Δ L, %	---	0	+5.5%	+15.3	
18181-B EVA, W/Primer	MOD	2,500	1.6×10^3	1.8×10^3	2.4×10^3	
	UT	905	1,070	900	1,150	
	UE, %	350	385	190	390	
	Δ Wt, %	---	+0.19%	+2%	+3.5%	
	Δ L, %	---	0	0	+1.3	
18181-C Polyethylene W/O Primer	MOD	8×10^4	1.2×10^5	1.2×10^5	1.2×10^5	
	UT	2,180	1,995	2,200	2,360	
	UE, %	~0	10	~0	0	
	Δ Wt, %	---	+0.52%	+1.4%	+2.5%	
	Δ L, %	---	0	0	0	
18181-D Polyethylene W/Primer	MOD	1.6×10^5	1.7×10^5	1.6×10^5	1.5×10^5	
	UT	4,340	4,235	4,380	4,490	
	UE, %	20	10	~0	0	
	Δ Wt, %	---	+0.31%	0	+0.6%	
	Δ L, %	---	0	0	0	

* Mechanical properties by ASTM D-638, 10"/Min rate of strain
 Δ Wt, % = percent weight gain ; Δ L% = percent length gain - tensile bar

HYDROTHERMAL AGING - GLASS BEAD FILLED
POLYMER SPECIMENS

TEMP. 60 °C

SPECIMEN NO.	PROPERTY *	CONTROL	100 HRS	250 HRS	500 HRS	2,000 HRS
18181-A EVA, W/O Primer	MOD	2,830	1.8×10^3	1.6×10^3	3.8×10^2	3×10^1
	UT	1,380	1,240	960	530	50
	UE, %	600	570	515	300	60
	Δ Wt, %	---	+0.92%	+29.3%	+410%	+2,015%
	Δ L %	---	0	+10.8%	+78.4%	+179%
18181-B EVA, W/Primer	MOD	2,500	2×10^3	2.5×10^3	2×10^3	1.6×10^3
	UT	905	935	930	990	830
	UE, %	350	445	285	315	120
	Δ Wt, %	---	+0.36	+4%	+6.3%	+34.7
	Δ L %	---	0	0	+6%	+12.5%
18181-C Polyethylene W/O Primer	MOD	8×10^4	1.1×10^5	1.4×10^5	1.1×10^5	8×10^4
	UT	2,180	2,230	2,510	2,070	2710
	UE, %	~0	5	~0	~0	~0
	Δ Wt, %	---	+0.6%	+1.4%	+2.5%	+4.8
	Δ L %	---	0	0	0	0 (a)
18181-D Polyethylene W/Primer	MOD	1.6×10^5	1.6×10^5	1.5×10^5	1.2×10^5	1.3×10^5
	UT	4,340	4,400	4,450		2,980
	UE, %	20	10	~0		~0
	Δ Wt, %	---	+0.33	+0.7%		+3.08%
	Δ L %	---	0	0	0	0

* Mechanical properties by ASTM D-638, 10"/Min rate of strain

(a) blistered appearance

Δ Wt, % = percent weight gain : Δ L% = percent length gain - tensile bar

HYDROTHERMAL AGING - GLASS BEAD FILLED
POLYMER SPECIMENS

TEMP. 80 °C

SPECIMEN NO.	PROPERTY *	CONTROL	100 HRS	250 HRS	500 HRS	1,000 HRS
18181-A EVA, W/O Primer	MOD	2,830	1.7×10^3	9.3×10^2	1.1×10^3	Removed (a)
	UT	1,380	460	285	310	
	UE, %	600	365	120	100	
	Δ Wt, %	---	+17.4%	+568%	+503%	
	Δ L %	---	+26.7	+109%	+96.2%	
18181-B EVA, W/Primer	MOD	2,500	2.2×10^3	2.3×10^3	3×10^3	1.7×10^3
	UT	905	987	1,010	910	725
	UE, %	350	275	245	220	140
	Δ Wt, %	---	+1%	+12.9%	+16.9%	+61.7%
	Δ L %	---	0	+2.7%	+5.6%	+21.5%
18181-C Polyethylene W/O Primer	MOD	8×10^4	1.2×10^5	1.3×10^5	1.3×10^5	1.2×10^5
	UT	2,180	2,145	2,160	2,110	1,930
	UE, %	~0	10	~0	~0	~0
	Δ Wt, %	---	+1.4%	+3.5%	+4.1%	+4.3%
	Δ L %	---	0	+0.2%	+0.4%	+0.6%
18181-D Polyethylene W/Primer	MOD	1.6×10^5	1.8×10^5	1.7×10^5	1.4×10^5	1.2×10^5
	UT	4,430	4,445	3,990	3,610	2,910
	UE, %	20	10	~0	~0	~0
	Δ Wt, %	---	+0.43%	+0.7%	+2.9%	+4.5%
	Δ L %	---	0	0	+2.2%	+0.2%

* Mechanical properties by ASTM D-638, 10"/Min rate of strain
 Δ Wt, % = percent weight gain ; Δ L% = percent length gain-tensile bar
(a) Specimens too soft to be tested, break on handling

DRIED (a)
SPECIMENS

HYDROTHERMAL AGING - GLASS BEAD FILLED
POLYMER SPECIMENS

TEMP. 40 °C

SPECIMEN NO.	PROPERTY *	CONTROL	100 HRS	500 HRS	2,000 HRS	5,000 HRS
18181-A EVA, W/O Primer	MOD	2.8×10^3	2.4×10^3	3.4×10^3	2.2×10^3	
	UT	1,380	1,205	1,280	1,210	
	UE, %	600	590	565	570	
	Δ Wt, %	---	---	---	---	
	Δ L %	---	---	---	---	
18181-B EVA, W/Primer	MOD	2.5×10^3	2.2×10^3	3×10^3	2.6×10^3	
	UT	905	965	990	860	
	UE, %	350	325	315	260	
	Δ Wt, %	---	---	---	---	
	Δ L %	---	---	---	---	
18181-C Polyethylene W/O Primer	MOD	8×10^4	1.8×10^5	1.6×10^5	1.5×10^5	
	UT	2,180	2,790	1,770	3,710	
	UE, %	0	~0	~0	~0	
	Δ Wt, %	---	---	---	---	
	Δ L %	---	---	---	---	
18181-D Polyethylene W/Primer	MOD	1.6×10^5	1.8×10^5	1.6×10^5	1.7×10^5	
	UT	4,340	4,720	4,571	4,380	
	UE, %	20	~0	~0	~0	
	Δ Wt, %	---	---	---	---	
	Δ L %	---	---	---	---	

* Mechanical properties by ASTM D-638, 10"/Min rate of strain
 Δ Wt. % = percent weight gain ; Δ L% = percent length gain -tensile bar

(a) Dried in circulating air oven ,105°C ,72 Hours

DRIED
SPECIMENS (a)

HYDROTHERMAL AGING - GLASS BEAD FILLED
POLYMER SPECIMENS

TEMP. 60 °C

SPECIMEN NO.	PROPERTY *	CONTROL	100 HRS	250 HRS	500 HRS	2000 HRS
18181-A EVA, W/O Primer	MOD	2.8×10^3	2.5×10^3	3×10^3	2.7×10^3	1.1×10^3
	UT	1,380	1,270	1,340	960	480
	UE, %	600	590	575	500	280
	Δ Wt, %	---	---	---	---	---
	Δ L, %	---	---	---	---	---
18181-B EVA, W/Primer	MOD	2.5×10^3	2.6×10^3	3.1×10^3	3.1×10^3	2.8×10^3
	UT	905	955	890	980	850
	UE, %	350	290	240	240	240
	Δ Wt, %	---	---	---	---	---
	Δ L, %	---	---	---	---	---
18181-C Polyethylene W/O Primer	MOD	8×10^4	1.6×10^5	1.7×10^5	1.8×10^5	1.8×10^5
	UT	2,180	2,580	3,680	3,050	2,680
	UE, %	0	~ 0	~ 0	~ 0	0
	Δ Wt, %	---	---	---	---	---
	Δ L, %	---	---	---	---	---
18181-D Polyethylene W/Primer	MOD	1.6×10^5	1.9×10^5	1.8×10^5	1.4×10^5	1.6×10^5
	UT	4,340	4,530	4,890	4,510	3,590
	UE, %	20	~ 0	~ 0	~ 0	0
	Δ Wt, %	---	---	---	---	---
	Δ L, %	---	---	---	---	---

* Mechanical properties by ASTM D-638, 10"/Min rate of strain
 Δ Wt, % = percent weight gain ; Δ L% = percent length gain-tensile bar

(a) Dried in circulating air oven, 105°C, 72 hours

DRIED
SPECIMENS (a)

HYDROTHERMAL AGING - GLASS BEAD FILLED
POLYMER SPECIMENS

TEMP. 80 °C

SPECIMEN NO.	PROPERTY *	CONTROL	100 HRS	250 HRS	500 HRS	2,000 HRS
18181-A EVA, W/O Primer	MOD	2.8×10^3	2.7×10^3	1.8×10^3	(b)	(b)
	UT	1,380	1,175	560		
	UE, %	600	545	290		
	Δ Wt, %	---	---	---		
	Δ L %	---	---	---		
18181-B EVA, W/Primer	MOD	2.5×10^3	2.6×10^3	2.6×10^3	2.8×10^3	2.6×10^3
	UT	905	905	920	1,020	880
	UE, %	350	240	310	405	260
	Δ Wt, %	---	---	---	---	---
	Δ L %	---	---	---	---	---
18181-C Polyethylene W/O Primer	MOD	8×10^4	1.4×10^5	1.8×10^5	1.7×10^5	1.8×10^5
	UT	2,180	3,160	3,280	2,440	3,010
	UE, %	0	~0	~0	~0	~0
	Δ Wt, %	---	---	---	---	---
	Δ L %	---	---	---	---	---
18181-D Polyethylene W/Primer	MOD	1.6×10^5	1.6×10^5	1.5×10^5	1.6×10^5	1.8×10^5
	UT	4,340	4,415	4,100	3,800	3,710
	UE, %	20	~0	~0	~0	~0
	Δ Wt, %	---	---	---	---	---
	Δ L %	---	---	---	---	---

* Mechanical properties by ASTM D-638, 10"/Min rate of strain
 Δ Wt, % = percent weight gain ; Δ L% = percent length gain - tensile bar

(a) Dried in circulating air oven ,105°C, 72 hours

(b) Broken, removed from further testing

POLYMER DIELECTRIC STUDIESProject No. 6072.1Polymer: EVA A9918Date: 11/6/84Notebook No. 18173Temp. 22 °C R.H. 43 %Description: Standard Encapsulant

TEST CONDITIONS

Equipment: Hi-pot 830BGeometry: Symmetric ☒ Asymmetric ☐Current: AC ☐ DC ☒Ground Polarity: Pos. ☒ Neg. ☐Operation: Auto ☒ Manual ☐

Electrode Dimensions:

Overload Current: 1 ma.Upper: 1/4" round, brass, 0.125" radiusRate of Rise: 500 V/sec.Lower: " " "

DATA

Test Number	Thickness mils	Breakdown K Volts	Strength Volts/mil	Notes
1	4.7	17.4	3700	
2	4.5	18.0	4000	
3	4.3	12.0	2790	
4	4.6	19.7	4280	
5	4.2	18.4	4380	
6	3.9	19.8	5080	
7	5.1	17.9	3510	
8	4.2	11.4	2710	
9	4.5	18.0	4000	
10	6.2	19.8	3190	
11	6.2	22.2	3580	
12	6.3	23.5	3730	
13	7.0	22.8	3260	
14	6.5	20.4	3140	
15	6.7	22.9	3420	
16	6.4	22.7	3550	
17	6.1	22.8	3740	
18	6.7	23.4	3490	

Continued

POLYMER DIELECTRIC STUDIESProject No. 6072.1Polymer: EVA A9918Date: 11/6/84Notebook No. 18173Temp. 22 °C R.H. 43 %Description: Standard Encapsulant

TEST CONDITIONS

Equipment: Hi-Pot 830BGeometry: Symmetric ☒ Asymmetric ☐Current: AC ☐ DC ☒Ground Polarity: Pos. ☒ Neg. ☐Operation: Auto ☒ Manual ☐

Electrode Dimensions:

Overload Current: 1 ma.Upper: 0.125" radius, brassRate of Rise: 500 V/sec.Lower: " " "

DATA

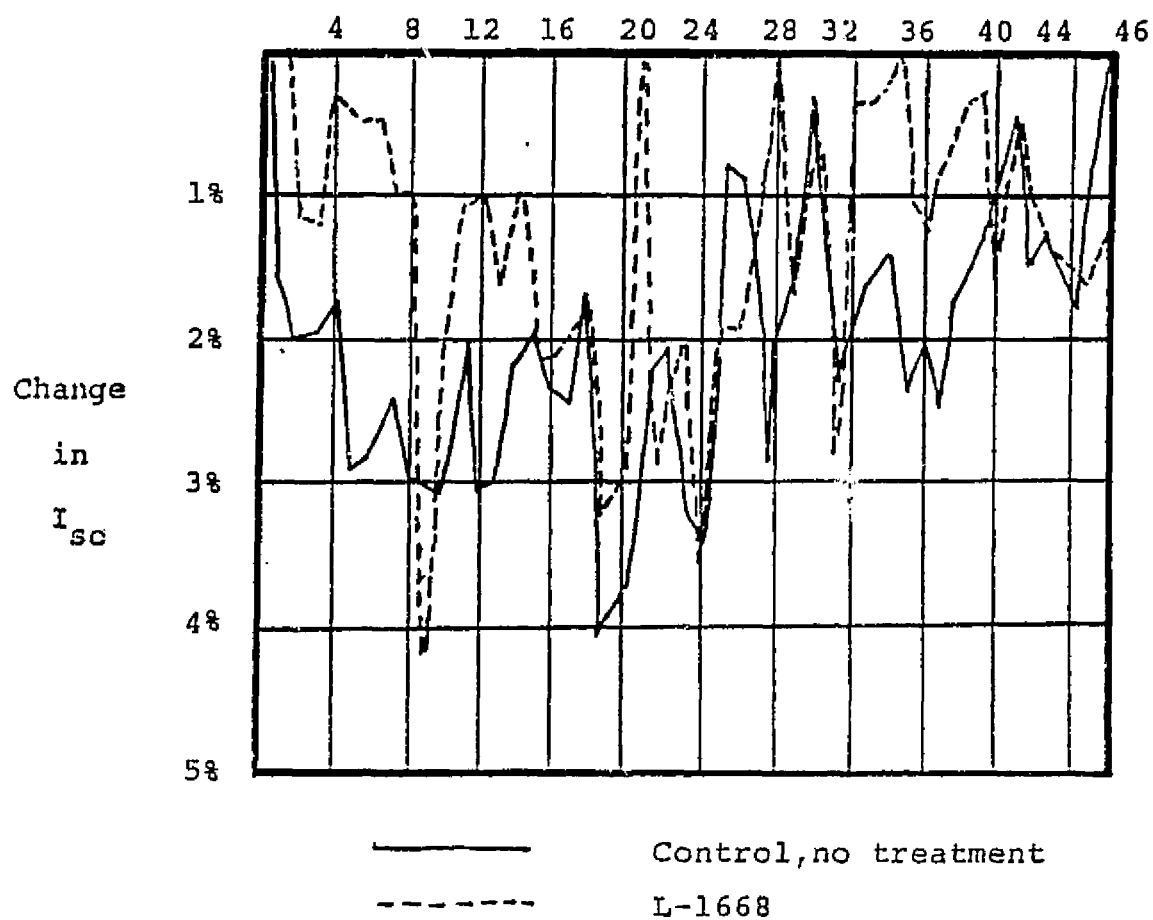
Test Number	Thickness mils	Breakdown K Volts	Strength Volts/mil	Notes
1	7.1	29.5	4150	
2	7.7	30.9	4010	
3	7.5	28.2	3760	
4	8.1	30.3	3740	
5	7.6	26.4	3470	
6	8.3	27.4	3300	
7	7.9	30.8	3900	
8	7.7	29.4	3820	
9	7.8	27.2	3490	
10	2.0	9.0	4500	
11	3.0	11.3	3770	
12	1.8	5.5	3060	
13				Run: 18173 Points: 20 Slope = 3.48 Intercept = 1.03 Correlation, r = 0.939
14				
15				
16				
17				
18				

SOILING EXPERIMENTS

SUNADEX GLASS

Percent change in short circuit
current after 46 months of outdoor
exposure, Enfield, CT.

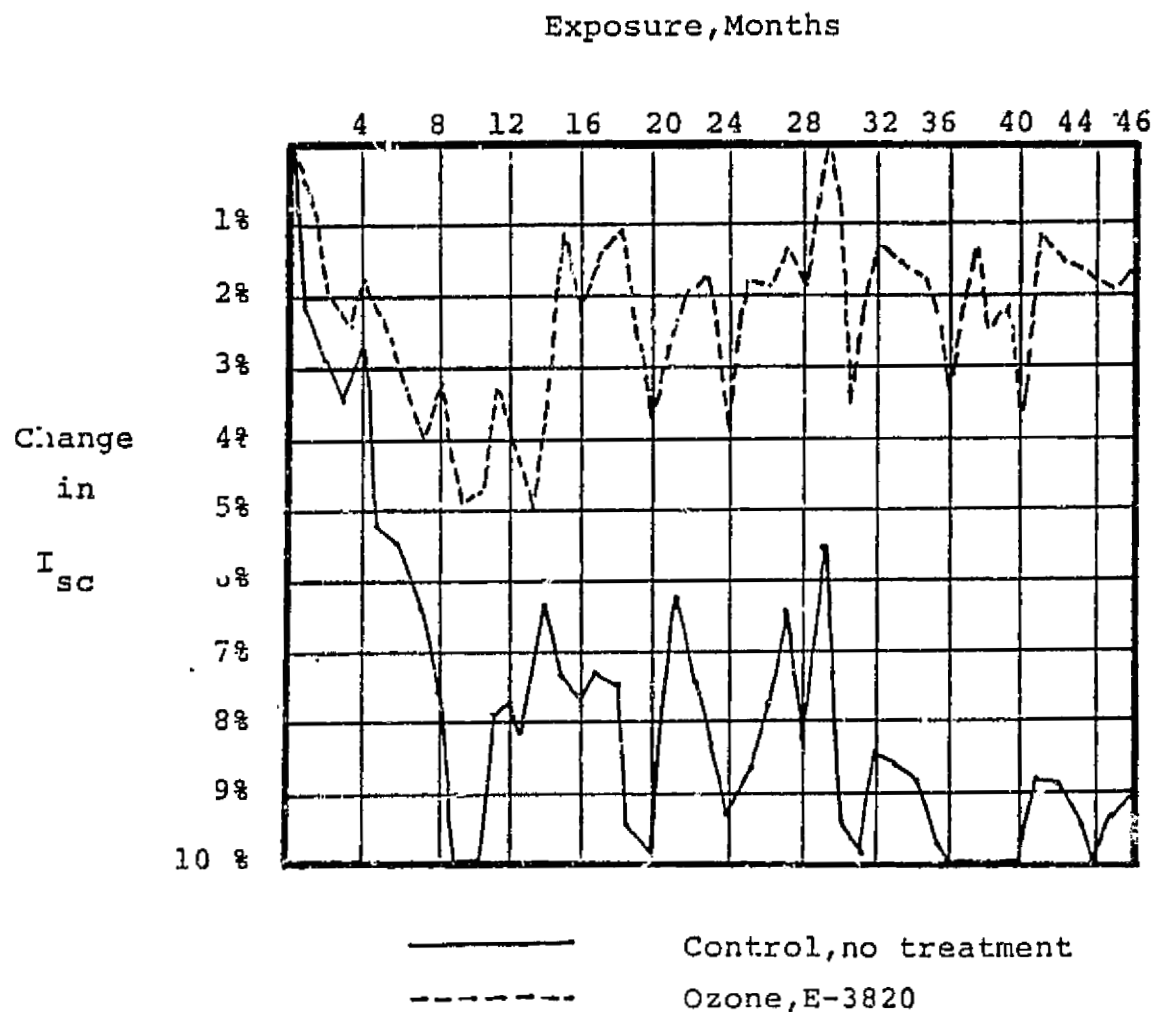
Exposure, Months



SOILING EXPERIMENTS

ACRYLAK FILM

Percent change in short circuit
current after 46 months of outdoor
exposure, Enfield, CT.

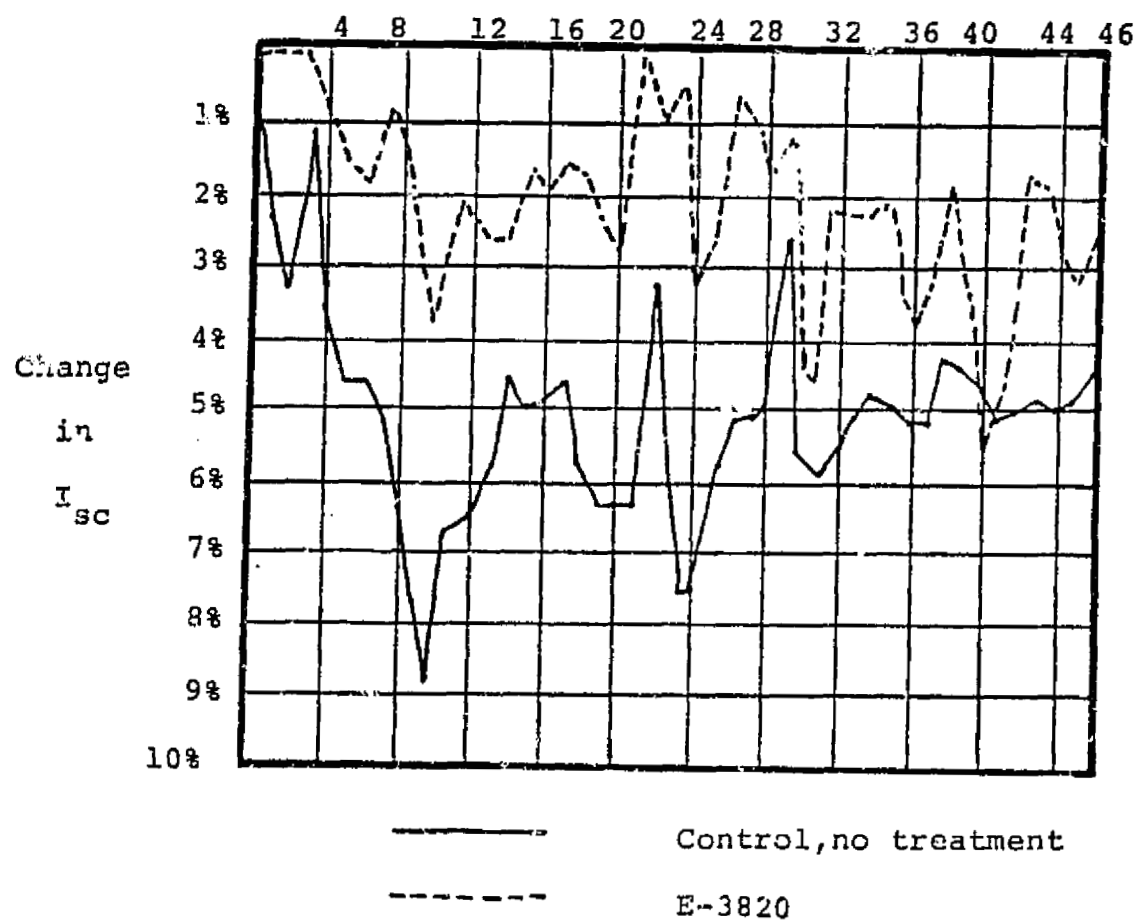


SOILING EXPERIMENTS

TEDLAR 100BG30UT
FILM

Percent change in short circuit
current after 46 months of outdoor
exposure, Enfield, CT

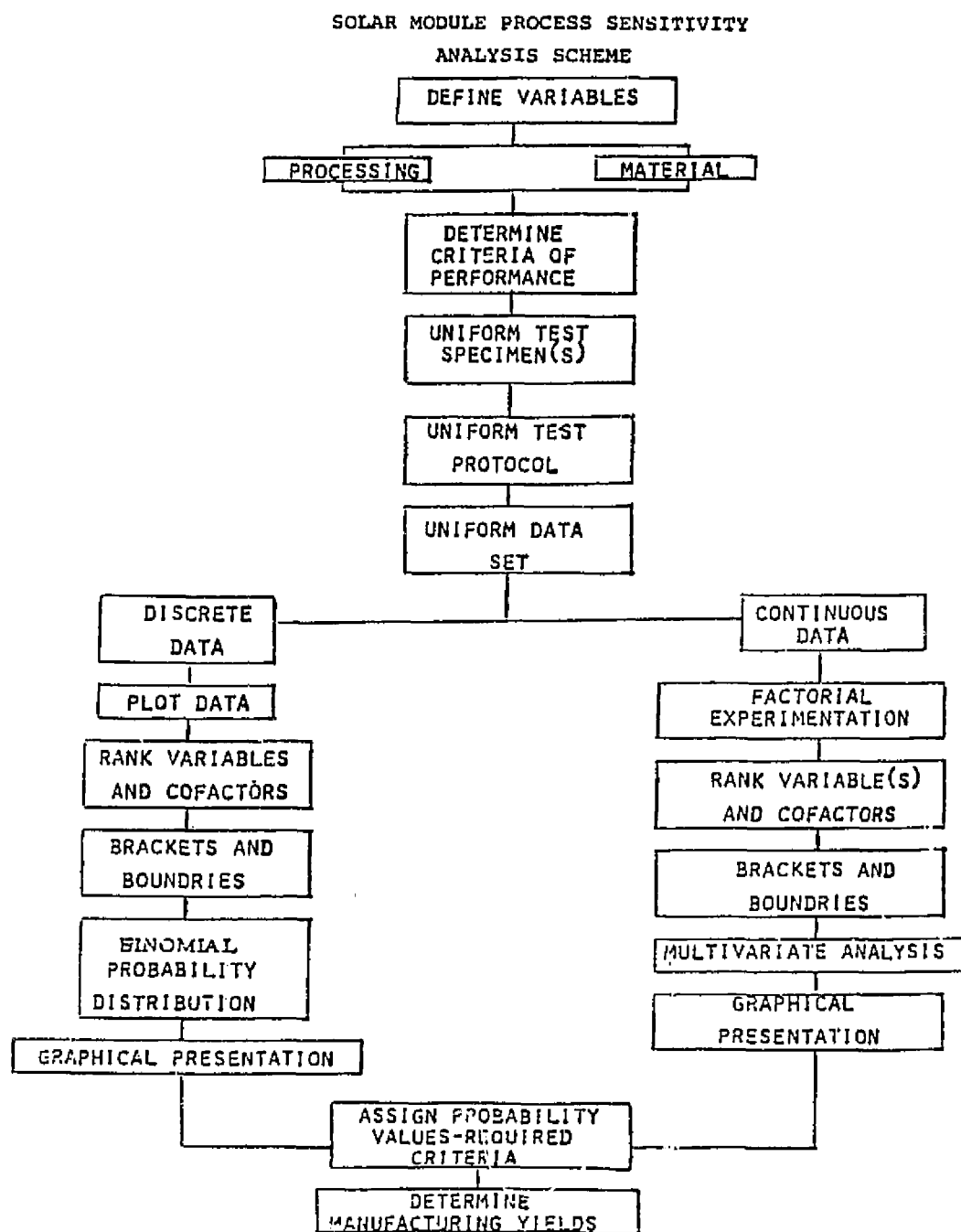
Exposure, Months



CANDIDATE SCREENING AND NON-SCREENING OUTER COVERS

Material	Chemistry	Thickness (inches)	Non-screen- ing Screening	n _D	Tear Strgth	Tensile	Ultimate	Optical		Cost ^c (\$/lb)	Density (gm/cc)	Cost \$ (as shown \$/ft ² /mil)	Cost (\$/ft ² /mil)
					ASTHD1004 (gm/mil)	Strenght (psi)	Elongation (%)	Trans ^a	%Pcell ^b				
Tefzel 280	ETFE	.005	N	1.403	634	6,500	200	85.6	89.2	14.50	1.7	0.64	0.128
Kynar- Oriented	PVF ₂	.0035	N	1.42	575	23,000	125	88.8	90.3	6.95	1.75	0.162	0.095
PFA 9705	PFA	.005	N	1.3	289	4,300	300	88.4	90.2	11.00 ^a	2.15	0.615	0.123
PEP 100	FEP	.002	N	1.345	289	3,500	300	93.6	94.8	9.75	2.15	0.218	0.109
Tedlar 110SG30TR	PVF	.001	N	1.46	530	17,700	100	-	-	11.90	1.5	0.085	0.085
Malar	ECTFE	.002	N	1.4	500	7,000	200	85.3	87.4	11.00	1.68	0.192	0.096

- a. estimated cost
- b. power transmission, standard single crystal silicon cell
- c. 1983 prices
- d. composite cost
- e. range: 350-900 nm



EVA CURE VERSUS PEROXIDE CONTENT

Percent Gel Resulting From Peroxide Content,
Cure Temperature and Dwell Time

		Gel Contents, %				
		Dwell Time, Minutes				
	<u>°C</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>30</u>
A9918 1.5 phr peroxide	120	0	0	0	0	0
	130	0	1.0	2.3	3.4	5.0
	140	12	24	60	64	68
	150	20	68	88	80	80
	160	73	83	80	80	80
No. -A 1.0 phr peroxide	120	0	0	0	0	0
	130	0	0	0	0	0
	140	V. low	4	5	54.7	65.6
	150	7.0	69.0	68.7	76.2	76.5
	160	73.0	75.5	78.2	84.1	82.5
No. -B 0.75 phr peroxide	120	0	0	0	0	0
	130	0	0	0	0	0
	140	4.2	2.8	2.5	35.2	63.5
	150	7.1	67.7	74.8	72.3	77.0
	160	6.0	70.9	74.6	79.2	82.0
No. -C 0.50 phr peroxide	120	0	0	0	0	0
	130	0	0	0	0	0
	140	3.1	3.1	2.0	5.0	79.2
	150	2.1	2.4	51.7	66.4	74.7
	160	6.0	65.7	73.9	74.9	76.2

PROCESS SENSITIVITY
JPL 6072.1

27.

Notebook No. _____ Run No. _____ Date: _____

OBJECT:

PROCESS CONDITIONS

1. Vacuum Pressure(line)	_____	in.Hg.
2. Evacuation time(before start)	_____	Min.
3. Starting temperature	_____	°C
4. Temperature ramp	_____	°C/Min.
5. Ultimate temperature	_____	°C
6. Backpressure, starting temp.	_____	°C
7. Backpressure, duration time	_____	Min.
8. Time at ultimate temp. ($\pm 5^{\circ}\text{C}$)	_____	Min.
9. Cooling rate	_____	°C/Min.

MODULE/SPECIMEN TYPE

1. Size	_____	5. Glass type	_____
2. Pottant formula	_____	6. Cell type	_____
3. Primer(to glass)	_____	7. No. of cells	_____
4. Primer(to cover)	_____	8. Cover Mtl.	_____

General Construction:

EVALUATION

Pottant	Bubbles (visual)	_____
	Gel Content	_____ %
	Swell Index	_____ %
	Discoloration (visual)	_____
	Spectroscopy (%T)	_____ %
Cells	Registration (visual)	_____
	Fracture (visual)	_____
	Continuity	_____ Ohms
Glass	Fracture (visual)	_____
Cover Film	Edge Shrinkage	_____ mm
	Tear/Puncture (visual)	_____
	Indented/Rippled (visual)	_____
Adhesion	Pottant/Glass	_____ Lbs/in
	Pottant/Cover	_____ Lbs/in

NOTES

Trouble Shooting Guide

The following is intended to serve as a checklist of technical considerations in the event that the lamination process and materials do not give the desired results.

Bubble Entrapment

- (1) Insufficient pump-down time under vacuum prior to the application of heat to the module. Trapped air bubbles.
- (2) Air trapped between the EVA sheets that becomes "sealed in" during module processing. Try using "Craneglas" non-woven glass cloth between the layers to provide an air exhaustion path.
- (3) Rate of heating too rapid. If thermal decomposition of the peroxide curing agent proceeds too quickly, its volatile by-products may form bubbles instead of diffusing throughout the resin.
- (4) Moisture or other volatile contaminant on the cell string, substrate, glass or other component. Are all components dry?
- (5) Premature pressurization of top chamber. If the top cavity is pressurized too soon, it may compress the molten resin and trap bubbles before they can escape.
- (6) Late pressurization of top chamber. If the top chamber is pressurized too late in the cycle, the high temperature may cause the volatile by-products of the cure process to form bubbles. Normally, the pressure load prevents this from occurring.

Low Gel Content (Low Cure)

- (1) Ultimate temperature too low. Is the thermocouple located such that it reads the EVA temperature? Thermocouples mounted on the outside of laminator or other locations cannot successfully predict resin temperature.
- (2) Too short a period of time at the cure temperature. The dwell time must be measured from the point at which the EVA reaches the desired cure temperature.
- (3) Temperature rate of rise too slow. The peroxide curing agent will decompose at low temperatures without the cure reaction taking place. Long, slow heating rates may seriously deplete the peroxide concentration before curing temperatures are reached.
- (4) Improper storage. The curing agent will slowly evaporate from rolls or sheets of EVA that have not been kept properly wrapped (in a plastic bag). Cut sheet exposed to the open air should not be used after a 24 hour period of time. Properly protected, the EVA has an indefinite shelf life.

Trouble Shooting Guide - Page twoDiscoloration (Yellowing)

- (1) Temperature too high. Excessive heat is the only processing condition observed to result in yellowing of the EVA. Is the thermocouple mounted in a location where the resin temperature may be measured? Are there any thermal hot-spots?

Lack of Adhesion (Delamination)

- (1) Too much primer applied. This is the most frequent cause of poor adhesion. Only a thin layer is necessary and excess primer serves as a parting agent instead of an adhesive.
- (2) Cleanliness. Is the glass and other components clean and free of oil, flux and other residues?
- (3) Primer prepared with solvent contaminated with water. A water-free grade of solvent should be used (anhydrous). Too high a water content will cause cloudiness or a precipitate to form in the bottle.
- (4) Primer too old. The primer solution slowly ages and loses its effectiveness. This is also indicated by the formation of a pink color and hazy appearance.
- (5) Insufficient cure of the EVA. The adhesion chemistry depends on adequate curing of the EVA. The adhesion chemistry depends on adequate curing of the EVA in order to develop maximum bond strength (see section on gel content).